Directional Solidification of Steel Castings

BY

R. WLODAWER
Suizo-Brothers Ltd.
Winterthur, Switzerland
(Central Department for Foundry Technique)

TRANSLATED BY

L. D. HEWITT

ENGLISH TRANSLATION EDITED

BY

R. V. RILEY
Chesterfield, England

PERGAMON PRESS
OXFORD - LONDON - EDINBURGH - NEW YORK
TORONTO - PARIS - BRAUNSCHWEIG
A translation, with substantial additions and amendments by the author, of the original volume
"Gelenkte Erstarrung von Metallen", Gieserrei-Verlag G.m.b.H., Düsseldorf.
# CONTENTS

**Foreword to the First Edition**  
ix

**Preface to the English Edition**  
xi

**From the Introduction to the First Edition**  
xiii

**Chapter 1. Introduction to the English Edition**  
1

1.1. The Technical Side of This Book  
1

1.2. The Psychological Side of This Book  
1

**Chapter 2. The Influence of Shape and Dimensions on the Time Taken for Castings to Solidify**  
2

2.1. Why Does a Casting Solidify? The Solidification Modulus  
2

2.2. The Solidification Time and Modulus of Large Plates  
3

2.3. The Influence of Mould Material and Casting Temperature  
4

2.4. The Practical Significance of Simplified Modulus Calculations  
4

2.5. Further Simplification of the Modulus Calculation by the Use of "Simulation" Bodies—Calculation of Junctions  
7

2.6. Practical Examples of Modulus Calculations  
11

**Chapter 3. The Thermal Gradient in the Casting**  
16

3.1. What Is a Thermal Gradient?  
16

3.2. Thermal Gradient and Difference in Modulus  
16

3.3. Effect of the Thermal Gradient on Solidification and Feeding Range  
17

3.3.1. Solidification Characteristics of Rectangular Section Bars  
19

3.4. Factors Influencing the Feeding Range  
21

**Chapter 4. Determination of the Connector Between Feeder and Casting (Feeder Neck)**  
23

4.1. Calculation of Transition Cross-sections between Feeder and Casting (without Allowing for the Effects of the Flow of Metal)  
23

4.2. Calculation of In-gates, Allowing for the Heating Effects of Metal Flow  
27

**Chapter 5. Feeder Heads**  
28

5.1. General  
28

5.2. Action of Open Feeder Heads  
29

5.3. Mode of Action of Blind Feeder Heads  
32

5.4. Behaviour of the Feeder Head during Solidification  
33

5.5. Shrinkage  
33

5.6. Calculations Giving the Shrinkage Cavity Characteristics of the Best Form of Feeder Head and the Compensating Factor  
35

5.7. Influence of the Structure of the Shrinkage Cavity on the Maximum Yield  
36

5.8. Feeder Head Calculations  
60

5.9. Examples of Feeder Head Calculation  
67

5.10. Other Methods of Calculating Feeder Heads  
67
CHAPTER 6. INCREASING THE THERMAL GRADIENT IN THE CASTING BY PADDING AND BY THE
UTILIZATION OF NATURAL END ZONES

6.1. Utilization of Natural End Zones and Shape of the Feeder. General
6.2. Use of the Heavers (41) Circle Method for Castings
   6.2.1. Use of the Circle Method for Extending Feeder Zones. Feeding of Bars and Boxes
   6.2.2. Application of the Circle Method to Junctions in a Complex Casting
6.3. Calculation of the Module Curve
6.4. Further Development and Simplification in Practice of the Methods of Heavers (41) and
   Stein (46)
6.5. Casting Sound Tubes

CHAPTER 7. INCREASING THE THERMAL GRADIENT BY MEANS OF MOULD HEATING PADS,
BREAKER CORES OR WASEBURN CORES

7.1. General Thermal Conditions Relating to Breaker Cores and Mould Heating Pads
7.2. Calculation of Washburn Cores and Mould Heating Pads on the Basis of the Thermal
   Conditions
   7.2.1. Calculation of Internal Feeders
7.3. On the Practice of Washburn Cores, Heating Pads and Internal Feeders
7.4. The Heating of Thin Sections of Moulding Sand. Influence on the Size of the Feeder
   Head. The Minimum Lengths of Ingots Which Will Prevent Harmful Sand Ejection Effects
   7.4.1. Harmful Effects of Hot Spots
   7.4.2. The Heating of Plane Core Plates by the Superheat of the Liquid Steel
   7.4.3. The Decrease in the Cooling Surface Areas of Core Plates as a Result of Heating
   7.4.4. Calculation of the Cooling Action of Cores in Long Tubular Bodies
   7.4.5. Calculation of the Cooling Action of Cores in Short Tubular Bodies (Discs and
   Rings)
   7.4.6. Retardation of the Solidification Period by Heating
   7.4.7. Checking the Calculations for Tubular Castings by Measuring the Solidification
   Time
   7.4.8. Retention of Heat in Junctions
   7.4.9. The Importance of the Heating Effect in Feeder Calculations
   7.4.10. Approximate Hub Calculations
    7.4.11. Special Features of the Heating Effect in the Placing of Blind Feeder Heads

CHAPTER 8. INCREASING THE THERMAL GRADIENT BY EXTERNAL COOLING (IRON CHILLS)

8.1. The Formation of Artificial End Zones by the Use of Chills
8.2. Measures Against Cracking Taken by the Use of Chills. Cooling of Junctions
8.3. Porosity at the Point of Attachment of Chills
   8.3.1. Porosity Caused by Chills
   8.3.2. Aids in Recognising Porosity Arising from the Molten Steel
8.4. Tears at the Points of Attachment of Chills
   8.4.1. Cracks Attributable to the Chills
   8.4.2. Cracks at the Point of Attachment of the Chill, Attributable to the Steel. Advice on
   the Control of the Steelmaking Process to Prevent Such Cracks
8.5. Principles of Calculating External Chills
   8.5.1. General
   8.5.2. The Apparent Reduction in Volume
   8.5.3. The Apparent Increase of Surface Area
   8.5.4. The Transfer of Heat at the Point of Application of the Chill
   8.5.5. Checking the Previous chill Calculations by the Experiments Reported by Brandt,
   Bishop and Pellini (38)
   8.5.6. Calculation the Necessary Chill Contact Surfaces
   8.5.7. Maximum Cooling Action on Simple Basic Shapes
   8.5.8. Chill Dimensions
   8.5.9. Summary
8.6. Operating Practice in Cooling Heavy Cross-sections by Means of Chills
8.7. Shrinkage Cavity Due to the Incorrect Placing of Chills
8.8. Use of Contoured Chills
12.4.3. The Design and Manufacture of Exothermic Sleeves. The Most Suitable Wall Thicknesses of the Sleeves 185
12.5. Practical Examples and Hints for the Use of Exothermic Feeder Heads 187
12.6. The Economics of Exothermic Feeder Heads 197
12.6.1. General 197
12.6.2. The Feeder Head Comparison; Making Use of the Characteristic 198
12.6.3. The Rapid Determination of the Most Economical Sleeve Wall Thickness 202
12.7. The Use of Exothermic Antipiping Powder 203
12.7.1. The Testing of Exothermic Antipiping Powders. The Structure of the Shrinkage Cavity in Covered Feeder Heads 203
12.7.2. On the Use of Antipiping Powders. Comparison with Exothermic Feeder Heads 208
12.7.3. Examples of the Use of Exothermic Powders 209
12.8.1. The Validity of Calculation Formulas Published up to the Present Time 212
12.8.2. True Physical Causes of the Extended Solidification Time 214

Chapter 13. The Use of Exothermic Pads to Increase the Thermal Gradient 214
13.1. Principles of the Calculation of Exothermic Pads 214
13.1.1. Heat Technology and General Principles 214
13.1.2. Principles of Feeding and Methods of Calculation for Exothermic Pads 215
13.2. Shape and Venting of Exothermic Pads. Heated Breaker Cores 218
13.3. Examples of the Use of Exothermic Pads 220
13.4. Frequently Occurring Defects with Exothermic Pads 228
13.4.1. Shrinkage Cavities Formed Because the Pads Have Been Made Too Thick 228
13.4.2. Blowholes Under Exothermic Pads 228

Chapter 14. Brief Note on the Use of Insulating Materials in Steel Castings 232

Chapter 15. Cavities in Steel Castings Which Are Frequently Confused with True Shrinkage Cavities 233
15.1. Blowholes Which Can Be Confused with Shrinkage Cavities 233
15.2. Slag Blowholes, Which Are Confused with Shrinkage Cavities 235

Chapter 16. Final Brief Word 240

Conversion Factors 244

Symbols Used in This Book 241

References 242
FOREWORD TO THE FIRST EDITION

It is of the utmost importance to be able to control reliably the solidification of steel castings and it is useless to employ the best qualities of steel if the resulting casting is not free from casting defects, such as shrinkage cavities and tears.

This book summarizes the results of a large number of investigations, mostly scientific in character, and develops them further from the practical aspect. It can serve in foundry operations as a basis for the directional solidification of steel castings. Diagrams, simple basic rules and formulæ provide the practical man with the means by which calculations can be avoided or minimized. He can interpret the required data from graphs. The book is therefore particularly suitable for the foundry manager, foreman and technician; it will also be useful for the designer, in giving him an idea of the influence of the design of his casting on the technical possibilities of producing it in the foundry. The theoretician will be interested mainly in the derivations of the laws and formulæ which are confined to separate sections and need not be studied in order to understand the practical sections. The commercial man can also obtain a general idea of the possibilities of steel casting design and the dangers to be avoided.

It is probably the first book of its kind, in which the problem of the directional solidification of steel castings has been treated comprehensively on a clear theoretical basis, accompanied by many practical examples.

A. Hvuvers
PREFACE TO THE ENGLISH EDITION

The author thanks the English-speaking technical world for the friendly reception it has given to his book dealing with feeding techniques in steel casting practice.

The field of gating and feeding technology is at present in a state of rapid development. The modulator method due to Chvojinov enables a deep, scientific insight to be obtained into the processes occurring during solidification, which, in combination with the latest results of research in many directions, such as the use of exothermic pads, has led to a revolution in feeding techniques.

Parts of the original manuscript (in German) of this book are already more than 15 years old. For this reason the English edition has been thoroughly revised and supplemented so as to bring it in line with the most recent developments.

As with all sciences, knowledge of this subject is never complete. However, the author hopes that he has been able to explain and illustrate the underlying theory in intelligible language, and to stimulate further development work.

Special acknowledgments are due to the publishers for the excellent translation and presentation of this book, and also to the firm of Salzer Bros. Ltd. of Winterthur, Switzerland, for their kindness in supplying such a large number of illustrations.

R. Wlodawer
FROM THE INTRODUCTION TO THE FIRST EDITION

Many excellent papers on feeding techniques have already been published; unfortunately most of them are scattered over many sources. For this reason well-established knowledge will be found here, as well as new information. For the sake of clarity this book will be based on the "classical" solidification theory of Chvoricinov(1), who was the first to introduce the concept of "directional solidification"; in this he was at least twenty years before his time, and he anticipated a great deal of knowledge which today is often described as "new"—unfortunately in many instances without any acknowledgement to Chvoricinov.

The author is particularly grateful to Verein Deutscher Gießereifachleute and to the Wirtschaftsverband Gießereiindustrie for their support in the publication of this book. With its publication it is hoped that a gap in the foundry industry will be filled. The author wishes success to all his readers in working through the book and putting its lessons into practice.

The Author

Werth bei Stolberg
(Rheinland)
1.1. The Technical Side of This Book

The quality demands made on castings have increased sharply in recent years and are becoming still more stringent. Foundries are faced by the need to produce high-grade castings, but nonetheless, to produce them economically. To do this, experimental castings are especially conducted for individual castings or small runs before mass production, are uneconomical.

Methods were therefore developed of analysing the physical processes occurring during the solidification of castings and then applying the appropriate practical measures. These methods stem from Chvorinov, who was the first to answer the basic question: How long does it take for a casting, or a given part of a casting, to solidify?

This method enables the feeding conditions in the casting to be determined with more certainty; this in turn results in less scrap, fewer repairs to castings, a more punctual timetable and economies in liquid metal.

The method can be used, for example, to calculate external and internal chill, exothermic materials, cooking and insulating mould materials, etc. by the simplest method.

By the term “modulus” is meant the ratio:

\[ \text{Modulus} = \frac{\text{volume}}{\text{cooling surface area}} \]

Many people are in the habit of calculating volumes and areas, and consider the computation of the modulus to be time-consuming. This view has even led to the substitution of other—supposedly simpler—methods.

However, it will be shown in this book that the modulus technique, after further development, is simple in conception, requires no additional calculation in many cases, and can be interpreted from diagrams.

Even with apparently intricate castings, the foundryman can always tackle the problem in terms of simple volumes and cooling surfaces so that the modulus method is a perfectly reliable guide.

In recent years, very vigorous development has taken place in the field of steel-casting technology, a development which is still continuing, especially in the case of exothermic materials. For this reason a great deal of new material is included in the present edition. The author is indebted to several firms, particularly to Sulzer Bros. Ltd., of Winterthur, Switzerland, for releasing material for the relevant illustrations. Numerous illustrations show very clearly the almost incredible possibilities existing in the field of steel-casting production.

It is important to know, not only how castings can be made satisfactorily, but also the reason for poor results. A great deal of space therefore is devoted to the description of defects. It is true that many defects have nothing to do with “new methods” but have always occurred. Here also the numerous illustrations will simplify the text for reference purposes. The author thanks the publishers for their sympathetic consideration of his requests for illustrations.

1.2. The Psychological Side of This Book

Steel founding, as shown here, can be taught and learned. It is psychologically understandable that many practical men, some of whom have twenty, thirty, or forty years experience behind them, treat new methods with distrust.

This attitude is completely unjustified. An old foundryman once confessed to the author: “Since I got to know Chvorinov’s method, many problems which I had been pondering over for years have suddenly become clear to me.” Can any foundryman claim honestly that he is never confronted by problems which require reflection?

For this reason the book is written in easily comprehensible language, and has two facets: all sections which are of importance for the practical foundryman are headed IMPORTANT FOR PRACTICE. The theoretical foundations for these sections are kept separate. These theoretical sections are intended for the casting designer and the students; if the practical man does not read them, the book will still remain comprehensible. It is certainly not a “Sunday lecture,” but must be worked through. With this in mind, the book has been provided with an unusually large number of practical examples, many of which have been worked out in detail.

The numerous aids which are to be found here should serve primarily as work preparation. “Work preparation” signifies previous consideration of what can happen afterwards. Scrap is usually found afterwards, and this is expensive. It is always cheaper to do some basic thinking beforehand, rather than cast scrap either once or even several times in succession.

Preparation takes time. “I haven’t got the time to
2.1. Why Does a Casting Solidify? The Solidification Modulus

Important for Practice

If 10 kg (Fig. 1) of steel is cast, first as a sphere and then as a thin plate, the plate will solidify much faster than the sphere. This is obviously because the heat contained in 10 kg (≈ 1300 cm³) is given off over a much larger surface area in the case of the plate, i.e., the larger the heat-emitting surface associated with a given volume, the faster the solidification. (A good example is the increased surface offered by the cooling fins on a motorcycle cylinder.) Chvotinov was the first to introduce the ratio volume/surface area into the solidification calculation; we will name this ratio the “modulus.”

A stepped wedge (Fig. 2) solidifies first at the thinnest step because its modulus is less than that of the next step. The thicker step serves as a feeder for the thinner one and “nourishes” it. Step 2 is in turn fed by step 3, and so on, the last step being supplied with metal by the feeder head. Thus, the feeder head supplies steel to the whole of the wedge by way of the individual steps, thereby providing metal to compensate for shrinkage cavities.

We have divided the stepped wedge into imaginary separate parts, and determined the appropriate solidification ratio—i.e., the modulus—of each step. The science of casting calculations is based on the subdivision of complex parts into simple basic components; the ratio modulus (M) = volume (V)/surface area (A) is then calculated for each component.

It must be borne in mind that this subdivision is only imaginary. The imaginary interface between two basic components is certainly not a cooling surface, so that it cannot enter into the calculation when determining the surface area.

Two bodies with the same modulus solidify in the same time. A cube as shown in Fig. 3 (length of side 3 cm, \(V = 3^3 = 27 \text{ cm}^3\), \(A = 6 \times 3^2 = 54 \text{ cm}^2\)) has the modulus \(M = \frac{V}{A} = \frac{27 \text{ cm}^3}{54 \text{ cm}^2} = \frac{1}{2} = 0.5 \text{ cm}^2\); in other words, a volume of 1 cm³ is associated with a surface area of 2 cm², from which the heat content of 1 cm³ of steel can be conducted away. This cube solidifies in the same
2.2. The Solidification Time and Modulus of Large Plates

(The later sections intended for the practical man can still be followed if this section is omitted.)

Comprehensive experiments and calculations by Chvorinow\(^{10}\) showed that the thickness \(X\) of the solidified layer after a time \(T\) obeys the following law:

\[
X = k \sqrt{\frac{T}{t}}
\]

where \(k\) is a constant dependent on the metal being cast and on the mould materials. According to the units of measurement selected, the expression for steel cast in sand or fireclay can be written:

\[
\begin{align*}
X_{(cm)} &= 0.053 \sqrt{\frac{T}{t}} \\
X_{(mm)} &= 0.684 \sqrt{\frac{T}{t}} \\
X_{(em)} &= 0.0885 \sqrt{\frac{T}{t}} \\
X_{(mn)} &= 0.085 \sqrt{\frac{T}{t}} \\
X_{(ft)} &= 0.273 \sqrt{\frac{T}{t}} \\
X_{(in)} &= 0.0514 \sqrt{\frac{T}{t}}
\end{align*}
\]

Solidification of the plate is complete when the solidified layers meet in the centre (Fig. 4). The thickness of each solidified layer is equal to half the plate thickness, or in other words the modulus of the plate. According to equation (1)

\[
T = \left(\frac{X}{k}\right)^2
\]

If \(T\) is the time taken for the plate to solidify, then \(X = M\), and

\[
T = \left(\frac{M}{k}\right)^2 = \frac{A}{k^2} \times M^2 = e \times M^2
\]

i.e. the time taken for a body to solidify is equal to the square of the modulus, multiplied by a constant \(e\), which is determined by the mould and metal materials.

This second-order relationship is represented in the log-log diagram (Fig. 1) as a straight line of slope 1:2.
3.1. The Influence of Mould Material and Casting Temperature

On the basis of theoretical calculations, it is generally assumed that the solidification rate of steel castings in permanently moulded moulds is influenced by the casting temperature. The factors that affect this rate include the heat transfer properties of the mould material, the chemical composition of the steel, and the size and complexity of the casting. Experimental results have shown that an increase in casting temperature can lead to a decrease in solidification time, which has implications for production efficiency.

The relationship between solidification time and casting temperature is often represented graphically. In the figure, the time of solidification is plotted against the casting temperature, with the data points corresponding to different mould materials and casting geometries. The graph indicates that for a given casting geometry, the solidification time decreases as the casting temperature increases.

The solidification process can be influenced by various factors, including the cooling rate, chemical composition, and physical properties of the steel and the mould material. Understanding these relationships is crucial for optimizing production processes and ensuring product quality.

Calculations

The practical significance of the simplified modulus calculations is highlighted in this section.

The modulus of elasticity is a measure of a material's resistance to deformation under stress. In the context of casting, it is important for determining the dimensional stability of the cast product. The formula for calculating the modulus of elasticity is:

\[ E = \frac{1}{\frac{1}{E_1} + \frac{1}{E_2}} \]

Where:
- \( E \) is the modulus of elasticity of the composite material
- \( E_1 \) and \( E_2 \) are the moduli of elasticity of the individual components

The modulus of elasticity can be calculated for different shapes and geometries, such as cylinders, spheres, and plates, using specific formulas that take into account the dimensions and material properties.

In summary, the influence of mould material and casting temperature on solidification time is a critical aspect of casting technology. Understanding these relationships is essential for optimizing production processes and ensuring the quality of cast products.
It is interesting to note that the moduli for the cube and its inscribed sphere or cylinder are the same, i.e., 4/3, where \( a \) is the length of side or the diameter. This signifies that each of these bodies takes the same time to solidify. It can be imagined that the corners of a cube solidify quickly, leaving a spherical, liquid body.

Many castings, as in Fig. 6, are made up of bars, which either form a closed ring or else have no cooling surfaces at the ends, as they merge into parts of the casting having heavier walls. (Rings, etc., are "semi-infinite" bodies, because although their thickness can be measured, they have neither beginning nor end.) A section of any given size (for example 1 cm long) taken in imagination from this bar, having sides of length \( a \) and \( b \), has a volume \( V = a \times b \times t \), and a cooling surface \( A = 2 \times t \times (a + b) \) (the imaginary surfaces of separation are not included in the calculation) and its modulus is

\[
M = \frac{V}{A} = \frac{a \times b}{2(a + b)}
\]

hence

\[
M = \frac{\text{cross-sectional area}}{\text{perimeter of the cross-section}}
\]

Simple determinations of an area and perimeter are thus substituted for troublesome calculations of volume and surface area. This principle is valid for bars of any given cross-section (cf. equation 4).

The moduli of bars of rectangular section can be read off from Fig. 7 without any calculation at all. The modulus curves are parallel in this log-log diagram.

Fig. 6. Very many castings are made up of bars, in which the end cooling surfaces are absent.

Fig. 7. Determination of the modulus of bars. The dimensions of \( a \) and \( b \) can be given in any required units (cm, in., etc.).
Let the original bar length \( P_M \) be equal to the perimeter of the rings 1, 2, and 3 obtained by bending, as measured at the neutral axis.

If \( P_M = 2\pi R_1 \), then

\[
P_A = 2\pi R_1 + 2\pi \frac{a}{2}
\]

and

\[
P_d + P_e = P_M
\]

i.e., when the bar is bent, the outer side elongates by the same amount by which the inner side contracts.

With further bending the ring becomes first a hollow cylinder, and finally a solid cylinder.

And \( P_1 = 2\pi R_1 - 2\pi \frac{a}{2} \)

As \( R_2 = \frac{a}{2} \) and \( P_M = 2\pi R_3 \), it follows that the bar formula can also be used to calculate the modulus.

Fig. 3. If an initially straight bar is bent, no change takes place either in the volume or surface area. Consequently the modulus of the bar also remains unaltered.

If a bar is bent round the neutral axis, as in Fig. 8, the total surface area remains unchanged, because the outer curved side increases by the same amount that the inner surface contracts. Rings of all types can thus be determined by the use of equation (1) or Fig. 7.

With further bending the hollow cylinder finally closes up to form a solid cylinder. The bar formula of Fig. 7 can still be applied; this can be seen from Table 2, where the modulus is calculated, first, by the bar formula and then by working out in full the ratio volume/surface area.

**Table 2. Calculation of the Modulus of a Solid Cylinder from**

1. The surface volume/surface ratio and
2. The bar formula (equation 5)

<table>
<thead>
<tr>
<th>Volume ( V = \pi r^2 h )</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface area ( A = 2\pi r h + 2\pi r b = 2\pi r (r + h) )</td>
<td>2</td>
</tr>
<tr>
<td>Modulus ( M = \frac{V}{A} = \frac{\pi r^2 h}{2\pi r (r + h)} = \frac{r h}{2(r + h)} )</td>
<td></td>
</tr>
<tr>
<td>Calculation according to equation (5) ( M = \frac{r h}{2(r + h)} )</td>
<td></td>
</tr>
<tr>
<td>Corresponding to the symbols on the cylinder: ( M = \frac{a b}{2(a + b)} )</td>
<td></td>
</tr>
</tbody>
</table>

| Both types of calculation give the same results, but it is simpler to determine the modulus by means of equation (5). |

We have still not exhausted the uses to which Fig. 7 can be put. As cubes, parallelepipeds, etc., have the same moduli as the inscribed cylinders, angular bodies can also be considered as cylinders of equal modulus, in accordance with Fig. 9, and their modulus determined. Even when a circle can only be inscribed approximately, this is still true to a fair degree of accuracy.

Many finite bodies with cooling faces can be determined by the bar formula, or can be read off on Fig. 7 without calculation; these two diagrams represent an important aid to the practical man in calculating the modulus, and, as will be shown later, the feeding or riser system.

Boses with an adjacent wheel disc (Fig. 10) can be conceived as bent bars with a non-cooling surface of width \( c \).

The corresponding formulae are derived in the table incorporated in the diagram. The mean boss diameter \( D \) is \( n \) times the thickness of the cross-section \( a \). The modulus is therefore, for \( D = a \times a \):

\[
M = \frac{V}{A} = \frac{a b}{2(a + b) - c - \frac{n + 1}{n}}
\]

From diameters of \( D = 3 \) to \( 4a \) onwards the boss becomes a ring, and the modulus approximates to:

\[
M \approx \frac{a b}{2(a + b) - c}
\]

At a diameter \( D = \infty \) the ring becomes a bar, and equation (3) then applies accurately.

With bosses which are not bored or with a small hole, \( D = a \), i.e., \( n = 4 \), and equation (6) becomes:

\[
M = \frac{a b}{2(a + b) - c}
\]

The validity of this equation was verified in Fig. 10 by comparing the result of the calculation using the
Fig. 9. Angular section bars and plates can be replaced for the purpose of calculating the modulus by the inscribed cylinder, which possesses the same modulus. The modulus can then be calculated from the formula $M = \frac{2b}{(R + b)}$ or can be read off without calculation from the diagram.

With plates or bars which are not exactly tetragonal, the average of the sides $a$ and $r$ can be taken as the diameter of the circle.

of the heat during the solidification of the steel, and their solidification behaviour is similar to that of the steel casting itself.

It can be calculated on the basis of the heat balance at a steel temperature of about 1600°C. (in accordance with Chapter 7.4) that this is the case for tubular bodies when the ratio of the outer diameter to that of the core is equal to 3.74, or in other words the core diameter must be about 27% of the outside diameter. This value can be less for rings and discs.

If the core is less than this amount, the tubular body must be calculated as if it were a solid when determining its modulus. Due to the danger of steel penetration and fusion, the core must then consist of a highly refractory mould material or be omitted altogether.

2.5. Further Simplification of the Modulus Calculation by the Use of “Simulation” Bodies—Calculation of Junctions

IMPORTANT FOR PRACTICE

If the beater cross casting (Fig. 11) is resolved into

Fig. 10. Calculation of the moduli of bosses, lugs, etc., casting in a wheel disc or housing wall.

ratio volume/surface area. This equation is used frequently in lugs, discs, etc. as well as bosses. The different positions of the brackets in equations (7) and (8) will be noted.

In the case of massive ring-shaped bodies with a small bore, the core can contain such a high proportion of the superheat of the steel that the core has reached a temperature of 1450 to 1480°C by the time the steel begins to solidify, i.e. the parts of the core heated in this way are unable to take up the corresponding part.
influence of shape and dimensions

Auxiliary Table in Fig. 14

Modulus calculations for the separate basic components of the better cross section. The calculation is begun at the end of the thickest part and is continued in the direction of the base.

<table>
<thead>
<tr>
<th>Component</th>
<th>Volume (cm³)</th>
<th>Surface area (cm²)</th>
<th>Modulus (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VII</td>
<td>V = 7.3 × 10 · 5.0</td>
<td>A₁ = 2 · 7.3 · 10 + 2 · 5.5 · 10 + 7.3 · 2</td>
<td>M₁ = 305</td>
</tr>
<tr>
<td></td>
<td>= 305</td>
<td>= 282</td>
<td>= 1.29</td>
</tr>
<tr>
<td>VI</td>
<td>V = 7.3 · 10 · 5.5</td>
<td>A₂ = 2 · 7.3 · 10 + 2 · 5.5 · 10 + 0.5 · 7.3</td>
<td>M₂ = 404</td>
</tr>
<tr>
<td></td>
<td>= 404</td>
<td>= 280</td>
<td>= 1.54</td>
</tr>
<tr>
<td>V</td>
<td>V = 7.3 · 10 · 6.0</td>
<td>A₃ = 2 · 7.3 · 10 + 2 · 6.5 · 10 + 0.5 · 7.3</td>
<td>M₃ = 425</td>
</tr>
<tr>
<td></td>
<td>= 435</td>
<td>= 270</td>
<td>= 1.57</td>
</tr>
<tr>
<td>IV</td>
<td>V = 7.3 · 10 · 6.5</td>
<td>A₄ = 2 · 7.3 · 10 + 2 · 6.5 · 10 + 0.5 · 7.3</td>
<td>M₄ = 475</td>
</tr>
<tr>
<td></td>
<td>= 475</td>
<td>= 260</td>
<td>= 1.79</td>
</tr>
<tr>
<td>III</td>
<td>V = 7.3 · 8.7</td>
<td>A₅ = 2 · 7.3 · 2 + 2 · 7.3 · 2 + 0.5 · 7.3</td>
<td>M₅ = 410</td>
</tr>
<tr>
<td></td>
<td>= 410</td>
<td>= 235</td>
<td>= 1.75</td>
</tr>
<tr>
<td>II</td>
<td>Based on the mean cylinder</td>
<td>A₆ = 13 · π · 2</td>
<td>M₆ = 2650</td>
</tr>
<tr>
<td></td>
<td>200 mm 8, 400 mm 15</td>
<td>= 881</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>V = 13 · 20 · π</td>
<td>A₇ = 13 · π · 2 - 3.7 Surface B = 4 · 7.3 · 2</td>
<td>M₇ = 2050</td>
</tr>
<tr>
<td></td>
<td>= 800</td>
<td>= 833</td>
<td>= 6.0</td>
</tr>
</tbody>
</table>

The basic components III to VII were calculated accurately in this instance, but the formula (5) would be adequate in practice, for example for component V: M = 2 × (7.3 · 10) - 1.65 cm²

For basic components, the "boundary surface" cannot enter into the calculation, as they are only imaginary. Nonetheless, the diagram of Fig. 7 can still be utilized in such cases, when the actual cooling surface is now only a fraction of the original geometrical surface, i.e., the modulus increases. The nomogram in Fig. 12 shows these changes of modulus. After some practice the proportion of "non-cooling surface" can be estimated (with the help of the table in Fig. 12).

As angular bodies and the round figures inscribed in them have the same modulus, they represent mutual "simulation" bodies, and either can be used for the calculation if any advantage is thereby obtained in computation. For example, the complicated bearing component of the housing shown in Fig. 14 can be circumstanced by a simple parallelepiped as a simulation. The size of this figure can easily be determined either from the drawing or, better still, from the pattern. The modulus is read off directly from the diagram of Fig. 7 and corrected from Fig. 12, where the parallelepiped adjoins other cross-sections. Even if the somewhat more complicated calculation of volume/surface area is preferred to Fig. 7 in such cases, the determination of the modulus of a parallelepiped is very simple.

The method of using simplified equivalent shapes is a technique of the greatest practical importance, and
A circle is first inscribed at the intersections (which occur very frequently), as shown in Fig. 15. In crossed places this circle gives the thickness of an equivalent plate with the same time of solidification as the intersection. The radius of the circle is therefore the required modules. With crossed bars the inscribed cylinder determines the equivalent bar with the same modulus, which can be read off from Fig. 7. This method is not theoretically accurate, but is sufficiently so for practical purposes.

The accumulation of heat in fillets increases with rising casting temperature. It is sufficient in practice to make an estimate of this influence. The procedure is basically as follows.

Draw the intersection on a scale of 1:1. Estimate the sand fill effect, based on the casting temperature. When this has been done, and only then, draw the inscribed circle which determines the modulus.

In most cases, however, it is sufficient to draw a fillet radius of \( r = \pi/3 \), and place the inscribed circle on this radius. Examples are shown in Figs. 16, 17 and 18.
FIG. 16. Determination of the junction modulus of a cover casing.

FIG. 17. Determination of the junction modulus of the strengthening web of a breech shell casing.

The junction consists of the intersection of two bars with a plate. It has approximately the same modulus as a substitution bar with a section 200 x 180 mm, but has two non-collinear faces (the interplants of plate 500).

FIG. 18. Determination of the junction modulus of a flange.

The junction has approximately the same modulus as a substitution bar 72 x 115, with a non-collinear face 30.

\[ M = \frac{7.2 \times 115}{2(7.2 + 115)} = \frac{828}{32.4} = 25.5 \text{ cm} \]
Practical Examples of Modulus Calculations

The results of solidification measurements at intersections are reproduced in Fig. 49, which is valid for steel containing ∼0.35% C. Figure 20 is derived from this diagram; it gives the corresponding modulus values for the intersections. It must be noted in both these diagrams that the geometrical corners are tangential to the inscribed circle, so that no allowance was made for the heating effect in the sand fillet. However, this effect can be significant, and this is discussed in more detail in Chapter 10.

2.6 Practical Examples of Modulus Calculations

IMPORTANT FOR PRACTICE

As the whole range of casting and feeder calculation is based on the determination of the modulus, the reader should attempt to work out some modulus calculations himself, using Figs. 22 to 34. The solutions obtained should be compared only when the results are all available. As soon as a certain amount of practice has been obtained in carrying out the processes of breaking down the casting into simple basic components, and simplifying the work as far as possible by constructing equivalent bodies or sections, it will be found that the modulus calculation itself will have become very simple.


![Diagram with measurements](image)

Fig. 23. Double flange.

Drive the junction 1:1 and inscribe a circle of about 240 mm diameter. Calculate the flange as a substitution bar 240 × 550 mm with a non-cooling surface of about 220 mm.

\[ M = \frac{15 \times 24}{2(15 + 24)} = 9.65 \text{ cm} \]

Calculation of the central portion: trapezoidal bases; the boundary surface as the flange and in the centre are non-cooling surfaces.

- Surface area: \[ \frac{22 + 15}{2} \times 29 = 308 \text{ cm}^2 \]
- Periphery: \[ \approx 20 + 30 = 50 \text{ cm} \]

\[ M = \frac{106}{50} = 2.12 \text{ cm} \]

![Diagram with measurements](image)

Fig. 22. Tuy.

The tuy corresponds to a sphere, as a close approximation

\[ M_{\text{sphere}} = \frac{D}{6}, \quad M = \frac{71}{6} = 12.5 \text{ cm} \]

![Diagram with measurements](image)

Fig. 21. Press plate (measurements include machining allowances).

Rapid calculation (approximate): Imagine the plate to be square, 700 × 700 mm, with a mass thickness of 180 mm (estimated). Calculate as in Fig. 7 for a semicircular radius R = 35; H = 18; M = 6.4 cm.

Accurate calculation (the T-slots with an obviously smaller modulus and the radiusing were not taken into account).

\[ V = (80 \times 90 \times 21) - (45 \times 30 \times 90) = 107,800 \text{ cm}^3 \]

Surface area \( A = (2 \times 8 \times 60) + 2(80 + 60) \times 95 + 2 \times 9(45 + 30) = 9600 + 7000 + 1350 = 17,950 \text{ cm}^2 \)

\[ M = V/A = 6.0 \text{ cm} \]
Fig. 25. Gear rim. (The dimensions include machining allowances.)

Required calculation: estimate the section in a bar 344 mm wide and with an average height of 83 mm, \( M = 3.6 \) cm from Fig. 7.
Accurate calculation: determine the modulus of the heaviest section, allowing for the non-cooling surface.

\[
M = \frac{22.9}{2(22 + 9) - 7.5} = \frac{198}{54.75} = 3.63 \text{ cm.}
\]

Fig. 26. Gear blank.

Draw the inner circle diameter = 1:1, and inscribe a circle ~100mm diam. The total bar of the rim has the dimensions 166 x 30, and \( M = 3.6 \) cm from Fig. 7. The hub cylinder is generated from a rotating area, once

\[
M = \frac{35 + 2.5}{2} = 36 = 681 \text{ cm}^2; P = 26 + 35 + 12 + 23 = 96 \text{ cm.}
\]

\[
M = A/P = 6.4 \text{ cm.}
\]

Fig. 27. Autoclave cover.

Bottom: curved plate, \( M = \frac{d}{2} = \frac{12}{2} = 6 \) cm. Flange: bar with trapezoidal section 26 x 35, non-cooling surface ~120.

\[
A = \frac{35 + 2.5}{2} = 36 = 681 \text{ cm}^2; P = 26 + 35 + 12 + 23 = 96 \text{ cm.}
\]

\[
M = A/P = 6.4 \text{ cm.}
\]

Fig. 28. Betting cup.

Middle section (extends at far as the re-entrant corner). Bar 3.0 x 15.0 cm.
from Fig. 7: \( M = 1.6 \) cm. Corner sections: simulating figure parallel-epiped 6 x 9 x 45; interface with the middle section is treated as a non-cooling surface; \( h = 230 \text{ cm}^2; d = 150 \text{ cm}^2; M = 1.25 \text{ cm.}
\]

Hints: in these and similar casings the modulus of inner section, reinforcement ribs, legs, etc., is frequently less than the modulus of the wall, in spite of first impressions to the contrary. This can be explained by the cooling of the corner section from three sides.
Fig. 26a. Practical example of a bearing cap as in Fig. 25. The modulus calculation has shown that the massive parts can be fed through the rectangular cross-section at A. If the modulus of the massive parts is somewhat too large for this to be done, this method can still be employed. (See Figs. 26b and c.)
(Courtesy Sulzer Bros.)

Fig. 26b. If the modulus of the massive parts is a little too large to feed it through the rectangular section, this section can be increased slightly by a shoulder at A.

Fig. 26c. If the modulus of the massive parts is too large, they can be cooled by chills, so that the rectangular cross-section at A will be adequate for feeding.
Fig. 29. Bearing block.

Draw the block 1:1 and inscribe a trapezoidal section body in one half. Determine volumes and surface area, allowing for non-cooling surfaces:

\[ V = 2600 \text{ cm}^3; \quad A = 941 \text{ cm}^2; \quad M = V/A = 2.2 \text{ cm}. \]

Second alternative: Insert in the half section a circle of about 120 diam. The pinion cylinder is obtained. (20 diam. \times 150 high) has approximately the same modulus at the centre of mass. If \( R = 6, H = 15 \), Fig. 7 gives a modulus \( M = 2.2 \text{ cm} \). The fixing leg is a parallelepiped \( 7 \times 4.5 \times 15 \text{ cm} \). Interface with the trapezoid is a non-cooling surface. \( V = 472 \text{ cm}^3; \quad A = 330 \text{ cm}^2; \quad M = 1.43 \text{ cm} \).

Fig. 30. Flange coupling.

Trapezoidal upper portion: \( A = \frac{41 + 28}{2} \times 28 = 660 \text{ cm}^2; \quad P = 28 + (41 + 28) \times 13 = 1154 \text{ cm} \). Interface with the middle portion is a non-cooling surface. \( M = A/P = 4.6 \text{ cm} \). Middle portion: plate about 12 thick; \( M = 42 \). Lower portion: inscribe a circle, allowing for the sand filled (estimated). Circle diameter \( \times 15 \text{ cm} \). The dimension bar \( (18 \times 14.5 \text{ cm} \) has a non-cooling surface with the middle section. \( A = 261 \text{ cm}^2; \quad P = 13 + 14.5 + 14.5 - 10 = 57 \text{ cm} \). \( M = A/P = 4.58 \text{ cm} \). Sufficient allowance is made for the small rise.

Fig. 31. Base plate.

Zone subdivision I to V.

I. Bar \( 40 \times 100 \text{ cm} \). Fig. 7, \( M = 20 \text{ cm} \).

II. Circular ring cast, interfaces with the plate are non-cooling surfaces:

\[ 25 \times 50 \]

\[ M = \frac{245 + 10 - 10}{2} = 9.6 \text{ cm} \]

III. Leg. Simulation body: parallelepiped \( 70 \times 80 \times 90 \text{ cm} \). \( V = 504000 \text{ cm}^3; \quad A = 2(70 \times 80 + 70 \times 90 + 80 \times 90) = 38200 \text{ cm}^2 \). Non-cooling surfaces: outer walls + ribs = \( 90 \times 8 \times 3 \) and plate = \( (70 + 80) \times 10 \). total \( 30600 \text{ cm}^2; \quad A = 38200 - 30600 = 7600 \text{ cm}^2 \). \( M = V/A = 4.5 \text{ cm} \).

IV. Leg. Simulation body: parallelepiped \( 100 \times 50 \times 50 \text{ cm} \). Rigid determination as a cylinder 95 diam. (\( R = 47.5 \)), \( H = 50 \text{ cm} \).

\[ M = 13.5 \text{ cm} \), from Fig. 7.

V. Strengthening bar. \( 45 \times 90 \times 180 \text{ cm} \). \( V = 738000 \text{ cm}^3; \quad A = 2(45 \times 90 + 45 \times 180 + 90 \times 180) = 62700 \text{ cm}^2 \). Non-cooling surfaces: outer walls + ribs = \( 8 \times 90 \times 4 \) = 2880 \text{ cm}^2. \( A = 45 \times 180 \times 10 = 2250 \text{ cm}^2 \). \( M = V/A = 12.8 \text{ cm} \).

VI. Seat bar. \( 25 \times 45 \); non-cooling surfaces at outer wall and plate.

\[ 25 \times 45 \]

\[ M = 3(25 + 45) - 8 - 10 = 0.21 \text{ cm} \].
**FIG. 32. Gate valve housing.**

Zinc solution:

Circular flange: bar 10 x 21 cm, 9 cm non-cooling surface; draw the intersection, inscribed circle 15 cm diam; simuation bar 15 x 21 cm. 

\[ M = \frac{13 \times 21}{2(15 + 21)} = 4.01 \text{ cm.} \]

Oval flange: intersection circle 10 cm diam.; non-cooling surface 5 cm²;

\[ M = \frac{2(10 + 14)}{10 \times 14} = 3.25 \text{ cm.} \]

Valve body: plate 5 cm thick; \( M = 0.22 = 2.3 \text{ cm.} \)

Intersection valve body in housing; inscribed circle 7 cm diam. Represents two round plates, intersection plate 7 cm thick, \( M = 0.22 = 3.5 \text{ cm.} \)

Intersection valve body (external fiber) inscribed circle about 5.5 cm,

\[ M = 0.22 = 2.7 \text{ cm.} \]

**FIG. 33. Auto hub.**

Zinc solution:

Nipple: taper A = \( \frac{2.7 + 5}{2} \times 10 = 37.5 \text{ cm}^3 \)

\[ P = 5 + 2.7 + 8.8 + \sim 11 - 27.5 \text{ cm, } M = A/P = 1.37 \text{ cm.} \]

Increment for non-cooling surfaces of the 16 ribs and lugs, estimated at \( -10\% \),

\[ M = 1.5 \text{ cm.} \]

Nose, bar: taper A = \( \frac{2.1 + 3}{2} \times 12 = 46.1 \text{ cm}^3 \)

\[ P = 4.1 + 3.1 + \sim 13 = 31.0 \text{ cm, } M = A/P = 1.45 \text{ cm.} \]

Increment; green basalt fiber; inscribed circle 1.8 cm diam,

\[ M = 0.6 \text{ cm.} \]

Intersection; green basalt fiber; inscribed circle 2.4 cm diam,

\[ M = 1.2 \text{ cm.} \]

Disc: bar 4 x 11 cm, non-cooling surface inner:

\[ M = \frac{(4 + 4)}{2} = 4.1 \text{ cm.} \]

Eye bolts on disk: cylinder 5.0 cm diam. x 6 cm H; non-cooling surface:

\[ M = \frac{2.2 \times 6}{2(2.5 + 6 - 4)} = 1.67 \text{ cm.} \]

**FIG. 34. Press cylinder.**

Zinc solution:

Cylinder: bar 65 cm diam.; side cooling surface above, at adjacent in seat; plate, \( M = 0.2 = 7 \text{ cm.} \)

Cup: plate, 10 cm thick; \( M = 0.2 = 5 \text{ cm.} \)

Cylinder body; plate 12 cm thick; \( M = 0.2 = 6 \text{ cm.} \)

Upper plate: 8 cm thick; \( M = 0.2 = 4 \text{ cm.} \)

Periphery of small drill holes 120 diam.; outer wall, plate 5 cm thick;

\[ M = 4 \text{ cm.} \]

Intersection; cylinder; sloping wall; inscribed circle, 18 cm diam.; two round plates,

\[ M = 0.2 = 3 \text{ cm.} \]
CHAPTER 3

THE THERMAL GRADIENT
IN THE CASTING

3.1. What Is a Thermal Gradient?

IMPORTANT FOR PRACTICE

The stepped wedge already mentioned (Fig. 2) solidifies at the thinnest position first. The metal in the thicker sections is still liquid at this time, and is therefore hotter and solidifies later. This is due to the difference in the amount of heat to be dissipated, and hence to the different modulus. Because the temperature falls towards the solidified extremity, a temperature gradient exists; a temperature gradient therefore develops when solidification progressively moves towards the riser.

According to Pellini, the temperature gradient in a plate must amount to at least 0.5°C/cm length of the casting, for a sound casting to be obtained; i.e. at this gradient each cm of the solidifying casting can still be fed from the part of the casting which is 0.5°C hotter (Fig. 35).

To obtain a temperature gradient it is sometimes (but not always) sufficient to pour through the feeder head

(Fig. 36) so that the coldest metal is found at the extremity of the casting, and the hottest in the feeder.

3.2. Thermal Gradient and Difference in Modulus

IMPORTANT FOR PRACTICE

In order for a cross-section to remain liquid longer than a neighbouring one, it must contain more heat. A section with a longer solidifying time also has a larger modulus. Experiments have shown that the modulus must be larger by a factor of about 1.1 for the section to be able to feed a thinner adjoining section. Feeder heads also form such metal-supplying sections. The feeder head modulus must be at least 1.2 times larger than that of the casting (Fig. 37).

\[ M_1 = 1.1 \times M_0 \]
\[ M_2 = 1.1 \times M_1 \]
\[ M_3 = 1.2 \times M_2 \]

Fig. 35. Thermal gradients on plates and bars, after Pellini.

Fig. 36. Temperature pattern immediately after casting in a plate which was top poured through the feeder.

Fig. 37. For satisfactory feeding the modulus of each cross-section, both within the casting and at the transition to the feeder head, must be 1.1 to 1.2 times that of the preceding modulus.
The principle that the feeder should solidify last is well known, but often too tightly and too generously dimensioned feeders are found together in one and the same foundry. The latter are usually based on the bad habit of designating all blowholes, even slag blowholes and pinholes, as shrinkage cavities, and, due to lack of knowledge of the correct method of determining riser dimensions, attacking the problem from the feeder side. The true cause—metallurgical variations in the steel—was ignored in this way, but the economic efficiency of the foundry operation is certainly jeopardized by over-large feeders.

3.3 Effect of the Thermal Gradient on Solidification and Feeding Range

**IMPORTANT FOR PRACTICE**

Metals solidify as crystals; in many metals the “tree” (dendritic) crystals grow from outside inwards. Figure 38 shows the growth of a dendrite. The more time there is available for crystal growth, the better the development of these starlike ramifications. Figures 39a-b show dendrites from a shrinkage cavity, while Fig. 40 illustrates a section with closely entangled crystals. In the spaces between these crystals are found the solidified remains of the liquid metal which was present just before solidification, and which is enriched in constituents remaining liquid at still lower temperatures.
According to Fig. 41 the solidification of a plate takes place in three phases: first, a solid edge zone is formed with a broad liquid region between the advancing crystal fronts; the liquid steel flows freely and always remains in contact with the dendrites, thus filling up the space which would otherwise be left as the solidified metal contracts. Secondly, the crystal peaks constrict the flow of metal and finally come into contact. Eventually the flow of molten steel is cut off and more or less extensive shrinkage cavities are formed (Fig. 42).

Wedge castings as in Fig. 43 do not exhibit parallel solidification fronts, so that feeding of the intercrystalline spaces is possible even with advancing solidification. A thermal gradient also produces a similar wedge-shaped solidification front. A plate as shown in Fig. 44 solidifies at the edges first, where the crystals grow more...
Effect of the Thermal Gradient on Solidification and Feeding Range

3.3.4. Solidification Characteristics of Rectangular Section Bars

Cooling proceeds on four or five sides at the end of the bar (Fig. 45), i.e., the solidification wedge is at first very steep and short, so that the length which can be adequately fed to give a sound casting is also short. The thicker the plates or bars, the farther the sides of the wedge can extend, and the longer the sound zones become (Fig. 46).

The transition from plate to bar is capable of infinite variations. Cochran investigated the feeding ranges of unalloyed carbon steels (0.2-0.3 per cent C), the results are shown in Table 3 and Figs. 47, 48, and 49.

### Table 3. Feeding Ranges on Cast Steel Plates and Square Section Bars

<table>
<thead>
<tr>
<th>End zone</th>
<th>Feeding zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2 + 2D</td>
<td>2D</td>
</tr>
<tr>
<td>T2 + 2D</td>
<td>4D</td>
</tr>
<tr>
<td>T2 + 2D</td>
<td>4.5D</td>
</tr>
<tr>
<td>T2 + 2D</td>
<td>With chills</td>
</tr>
<tr>
<td>T2 + 2D</td>
<td>Without</td>
</tr>
</tbody>
</table>

A bar from a width ratio of 1:5 counts as a plate. The use of chills is explained in Chapter 8.
By using highly exothermic antipiping materials the length of the sound feeder zone increases, because the thermal gradient is increased as a result of additional superheating in the feeder head (Fig. 50). This will be discussed more fully in Chapter 12.

By placing chills in the faces of plates the end zone lengths can be increased by about 50 mm compared with Fig. 48. A similar increase of about 50 mm can be obtained by simulating end zones (by means of a chill placed between two feeding points—see Chapter 8 and Table 3).

The end zone lengths of bars are also increased by means of an end chill: The increase in this case is so slight, however, that it is better on safety grounds not to allow for it in the calculation.

The region of the casting which can be supplied by a single feeder head is known as the feeding area; it is only necessary to place a single feeder inside one feeding area. A second feeder would not only be wasteful (Fig. 54), but in some circumstances could even cause...
Factors Influencing the Feeding Range

damage. If one of the two feeders is only a little less than the other, it solidifies first and draws some metal from the larger one, which will then empty more completely, so that the shrinkage cavity can extend into the casting.

Feeding areas which are bounded by end zones are significantly larger than those without end zones (Fig. 52).

Fig. 52. Subdivision of a flange into feeding areas.

The casing in question, according to its shape, is divided into one or more feeding areas, and a feeder of suitable size placed in each area.

5.4. Factors Influencing the Feeding Range

Feeding becomes more satisfactory as the angle of the wedge between the solidification fronts increases. As the crystals themselves grow with a dendritic and therefore wedge-shaped structure, an angle is also formed between the crystals. The longer the crystals are (with the same base width) the smaller this angle becomes and the more difficult it is for the molten steel to reach the shrinkage cavities forming between the numerous crystallites (Fig. 53).

In the region of the growing crystals solid components (crystals) and liquid metal exist side by side. This zone is neither solid nor liquid, but is mushy, and is known as the "solidification band". The wider this band, the longer the crystals, and the more difficult feeding becomes. The width of the solidification band is influenced by the following circumstances:

1. The phase diagram of the metal indicates the interval during which solid and liquid metal exist together (the freezing range). The wider this interval, the longer the time available for the crystals to grow, and the more favourable the solidification pattern becomes (Fig. 54).

Fig. 53. Influence of the wedge angle between the crystals.

1. Wedge-shaped intersections are formed between the dendrites. The larger the wedge angle between the solidification fronts, the shorter the crystals and the more favourable the feeding conditions.

2. Freezing range small. Short crystals, large wedge angle between the crystals, feeding easy, even towards the end of solidification.

3. Freezing range large. Long crystals, small wedge angle between the crystals. Feeding difficult, especially towards the end of solidification, when the crystal peaks are almost in contact and only a small main channel is still present.

Fig. 54. Influence of the freezing range on the width of the crystallite solidification band.
(2) The higher the solidification temperature, the more rapidly the temperature falls (hotter bodies radiate heat much more than cooler objects). With a high solidification temperature, therefore, the crystals have little time to increase in length, as the molten metal in the interstices will also solidify rapidly; the freezing range is small, and hence favourable to the production of sound castings (Fig. 55).

(4) The more intensive the chilling (the heat absorption capacity and thermal conductivity) of the mould material, the more rapidly the heat will be withdrawn from the residual melt and the more rapidly will solidification proceed; the solidification band is again smaller and more favourable (Fig. 57).

(3) The lower the thermal conductivity of the metal, the more the dendrites use up their store of heat during growth. With a low thermal conductivity heat is only slowly replenished from the residual melt. Growth is hindered, the crystal length is short, and the freezing range is again short, and therefore favourable (Fig. 56).

Points (1) to (3) are dependent on the metal and cannot be influenced by the foundryman. Improvements can be achieved only by selecting a more suitable mould material.

Every metal therefore exhibits a characteristic solidification pattern which can be influenced by the mould material, and also to some extent by the design of the casting, for example, a slowly solidifying sphere or a rapidly solidifying thin plate (Fig. 58).

The longer the time available for the dendrites to grow, the longer they will become, and the wider will be the solidification band (see also Fig. 4). Consequently very wide solidification bands exist in the interior of thick-walled castings, making satisfactory feeding difficult. Beyond a certain thickness the dendrites become so long that the interstices between the crystallites can no longer be fed to produce a sound casting (leading to unavoidable central segregation or microporosity in massive castings).

The decreasing feeding range in thick-walled plates are also shown in Figs. 57 to 59.
CHAPTER 4
Determination of the Connector Between Feeder and Casting, Here Called Feeder Neck
(earlier known as the ingate, neck, shoulder, etc.)

4.2. Calculation of Transition Cross-sections between Feeder and Casting (without Allowing for the Effects of the Flow of Metal)

IMPORTANT FOR PRACTICE

Directional solidification must take place from the casting and across the ingate to the feeder, with an increase in modulus of about 50 per cent at each stage:

\[ M_{\text{casting}} : M_{\text{neck}} : M_{\text{feeder}} = 1 : 1.1 : 1.2 \]  \hspace{1cm} (9)

If this condition is satisfied then shrinkage cavities cannot occur near the feeder neck.

Unfortunately this rule is often broken (Fig. 59),

![Diagram showing formation of cavities due to the construction of the feeder neck towards the casting.]

As the modulus of the neck at the nearest point is only \( M = 3.2 \) cm, it freezes prematurely bare, leading to shrinkage cavities in the flange.

leading in every case to premature solidification of the ingate, with the formation of shrinkage cavities.

The gate formula given by Namar(46):

\[ M_{\text{gate}} = \frac{a \times b}{a + b} \geq M_F \]  \hspace{1cm} (10)

supplies values which are too low; practical experience has shown that cavities are produced, and consequently the formula cannot be recommended.

Over-dimensioning of the neck can also lead to scrap due to the formation of secondary shrinkage cavities.

According to Fig. 60 every neck is a semi-infinite bar, because the end cooling surfaces are missing due to the adjoining feeder and casting. The modulus is therefore calculated by the bar formula or from Fig. 7. Because these parts often have very irregular shapes (Fig. 61), the greatest care must be taken to ensure that

![Diagram showing representation of the feeder neck as a semi-infinite bar.]

![Diagram showing rapid determination of the dimensions of an irregularly shaped feeder neck, using Fig. 7.]

Fig. 60. Representation of the feeder neck as a semi-infinite bar.

Fig. 61. Rapid determination of the dimensions of an irregularly shaped feeder neck, using Fig. 7.
the modulus remains the same throughout the neck. Figure 7 is an almost indispensable guide for this purpose.

The necessary modulus cannot be achieved solely by widening the gate, especially in plate-like castings; this fact is illustrated in Fig. 62. Only an enlargement in cross-section, as in Fig. 63, can produce correct solidification; according to the size of the enlargement in cross-section the ingate can even contract towards the casting (Fig. 63, Example 2). These examples are not to be confused with the wedge-shaped pads to be described later.

Flanges, etc., often form junctions with a larger modulus. Obviously the ingate must be attached at these positions (Fig. 64, Example 2). Enlarged necks are absolutely necessary in this case.

---

**Fig. 62.** The necessary modulus cannot be attained in plate-shaped castings merely by widening the neck.

---

**Fig. 63.** Neck to a 30 mm thick plate; the modulus is correct due to enlargement in section.

---

**Fig. 64.** Double flange with a correctly and incorrectly dimensioned neck.

---

**Fig. 65.** Feeder neck of a distributor casting. Possibility 2: feeder more easily removable than in 1 (Fig. 66a).

Feeding each of two flanges by means of a single feeder boss at the side. Alternatives 1 and 2 are encountered mainly in fittings with flanges closer together than those shown in this example.
Fig. 66a. Feeder neck of a distributor casting. Alternative 1: feeding each of two flanges by a single feeder head.

Fig. 66b–d. Illustrative examples of necks for fittings.

(b) Valve housing (a feeder with an exothermic sleeve on the valve seating).

Fig. 67. Neck of a distributor casting. Alternative 3: separate, easily removable feeders.

(c) Gate valve housing.

Fig. 68. Neck of a distributor casting. Alternative 4: feeding through open feeder head.
TABLE 4. DETERMINATION OF THE FEEDER NECKS OF A DISTRIBUTOR CASTING

<table>
<thead>
<tr>
<th>Flange</th>
<th>( M_1 = \frac{6 \times 2.5}{2(6 + 2.5) - 1.5} ) = 0.97 cm&lt;br&gt;Associated neck: ( M_{n1} = M_1 \times 1.1 = 1.07 ) cm</th>
<th>Flange II</th>
<th>( M_1 = \frac{6 \times 3}{2(6 + 3) - 1.5} ) = 1.1 cm&lt;br&gt;Associated neck: ( M_{n2} = M_1 \times 1.1 = 1.21 ) cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fig. 65</td>
<td>( a = 5 ) cm&lt;br&gt;( b = 4 ) cm</td>
<td>( 40 )</td>
<td>( 45 )</td>
</tr>
<tr>
<td>66</td>
<td>( a = 5 ) cm&lt;br&gt;( b = 4 ) cm</td>
<td>( 50 )</td>
<td>( 45 )</td>
</tr>
<tr>
<td>67</td>
<td>as Fig. 66</td>
<td>as Fig. 66</td>
<td></td>
</tr>
<tr>
<td>68</td>
<td>( a = 3.5 ) cm&lt;br&gt;( b = 6 ) cm</td>
<td>( 45 )</td>
<td>( 50 )</td>
</tr>
</tbody>
</table>

\( a \) is assumed on the basis of the junction circle<br>\( b \) is then determined by using Fig. 7.


FIG. 71. Feeding possibilities of a cylinder. For method of calculation see Table 5.
Calculation of ingates, allowing for the heating effects of metal flow

Table 5. Determination of the Feeder Necks of a Cylinder, According to Fig. 71

<table>
<thead>
<tr>
<th>Modulus of the cross-section</th>
<th>Modulus of the neck</th>
<th>Feeder determination (see Chapter 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simulation body:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Square section bar, with walls 60 and 70 mm, omitted as non-cooling surfaces</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$M_I = 11 \times 11$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$= \frac{2(11+11) - (6 + 7)}{ } = 3.9$ cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
<td>---------------------</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand fillets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Allowing for the sand fillets a cylinder of 200 mm dia. x 100 mm high is assumed. The wall 50 mm is omitted (non-cooling surface)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>According to equation (5):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$M_{II} = \frac{12.5 \times 10}{2(12.5 + 10 - 5)} = 3.55$ cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>III</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The cylinder sleeve is a curved plate of thickness $d = 30$ (at the thickest point) the modulus $M_{III} = \frac{d}{2} = 3.3$ cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculation of the ingate not necessary with an open feeder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feeder determination (see Chapter 5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$M_{I} = 1.2 \times M_{III} = 4.0 \times 3.0 = 12.0$ cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$M_{II} = 1.2 \times M_{II} = 4.25$ cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$M_{III} = 1.2 \times M_{III} = 4.3 \times 3.9 = 18.3$ cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open feeder:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$M_{FE} = 1.2 \times M_{III} = 4.25$ cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>from the feeder table for $H = 5$ diam, diam$_P = 250$, $N_P = 345$ mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control of the modulus gradient: $M_{I} : M_{II} : M_{III} : 3.0 : 3.5 : 4.0$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figures 65 to 71 show various examples in the design of ingates for pipe fittings; the necessary calculations are summarized in Table 4. When possible one feeder head should supply two flanges (to improve the metal yield). Chills are usually necessary for high-quality pipe fittings which are required to be tested radiographically (see Chapter 8). The cost of removing the feeder must also be taken into account when placing the neck; these costs vary according to the operation. A further example is illustrated in Fig. 71, with Table 5.

4.2. Calculation of Ingates, Allowing for the Heating Effects of Metal Flow

**Important for Practice**

Some of the superheat of the steel is lost to the mould walls while the metal is flowing, i.e., the walls absorb heat, thus reducing the directional cooling effect during solidification. The greater the superheat and the longer the period of flow through the section in question, the more pronounced this effect becomes. The safe utilization of this effect depends on the casting being satisfactorily supplied with metal by the feeder head. With one feeder head this is always true, but with three feeders special provisions must be made in the runner system. According to Chvorto

$$T_f = 1.15 \frac{T_s}{T_0}$$

where $T_f$ is the time of solidification with, and $T_0$ without, metal flow. The equation is valid for superheats normally encountered in practice. In addition:

$$\frac{T_L}{T_0} = \frac{(M_{I})^2}{(M_0)^2} = 1.15 \frac{T_s}{T_0}$$

whence $M_f = 1.07 M_0$

This signifies that the modulus of cross-sections through which hot metal is flowing is increased only by 7 per cent by virtue of this flow of metal; for ingates of this type therefore the following relationship is valid:

$$M_{casing} : M_{feeder} : M_{feeder} = 1 : (1.0 - 1.03) : 1.2$$

in which the ratio 1.0 applies only to strongly superheated small parts (70-100°C superheat).

If the given examples of pipe fittings (Figs. 65-68) are recalculated, the ingate dimensions are now reduced by 2-3 mm, i.e., by a far lesser amount than is frequently assumed. Very often obviously under-dimensioned necks are justified on the grounds of hot metal flow, and castings being produced some time and time again from this cause. The shrinkage cavities are then falsely attributed in many cases to the provision of too small a feeder; this is then enlarged, the yield deteriorates, the defect is not eliminated and the feeding system as such is often abandoned.
CHAPTER 5

FEEDER HEADS

5.1. General

Important for Practice

Chapter 5 is concerned with feeders in which highly exothermic anti-slip piping material is not used, either in the form of sleeves or powder. Low-exothermic materials, which allow of no reduction in the size of the feeder, must be used with open feeder heads.

The mathematical basis for Chapter 5 is discussed in Section 5.6, so as not to interfere with the reading of the practical sections.

5.2. Action of Open Feeder Heads

Important for Practice

According to Fig. 72, a shrinkage cavity is formed during solidification in a casting not supplied with a feeder, a considerable vacuum being generated. The pressure of the atmosphere drives the liquid metal from an attached feeder into this cavity, and the pressure energy is required to overcome the resistances to flow, which become very high towards the end of solidification and determine the feeding ranges.

A pressure column of liquid steel 1.45 m high with a specific gravity of 7 exerts a pressure of one atmosphere. The great majority of feeders have heights much less than this, and thus exert relatively little downward force. The expression "gravity feeder head" which is occasionally used is therefore misleading. Once the flow to the junction with the body of the casting is interrupted prematurely (because of incorrect dimensioning of the feeder neck or casting) then even 100 atm pressure could not force liquid metal through the solidified cross-section. It is therefore quite wrong to blame low feeder pressure for scrap which is actually caused by thermal effects. The usual language of the foundryman is inaccurate and misleading in this respect. Shrinkage cavities should refer to cavities which lack in liquid steel. In this way, false inferences based on incorrect terminology will be avoided, because the steel can no longer flow exactly as it would under the action of atmospheric pressure.

Premature freezing of the surface of the feeder head (Fig. 73) leads to the formation of secondary cavities (because the liquid metal is cut off from the pressure of the atmosphere) which otherwise can penetrate deeply into the casting. The temperature gradient of the feeder must therefore increase towards the top. Methods of accomplishing this are shown in Fig. 74. The procedure using pinched cores, adopted by Pearson,10 from the atmospheric feeder head, also merits consideration (Figs. 75, 76). It is remarkable that the atmospheric...
pressure acts via the core against gravity, even when the surface of the feeder has solidified (see also Fig. 79). Small feeders with a puncture core are more effective than larger feeders without one.

5.3. Mode of Action of Blind Feeder Heads

**IMPORTANT FOR PRACTICE**

The sphere has the smallest radiating surface area of any body of equal volume, and represents the ideal feeder shape as far as thermal conditions are concerned. From the point of view of moulding technology the production of spherical feeders is costly (Fig. 77). Shapes approximating to spheres are cheaper to mould (Fig. 78).

A thermal gradient feeder-casting is generated by all these measures.

---

**Fig. 77. Manufacture of spherical feeders by means of cores.** This method of moulding is expensive, but is occasionally used with high-grade steels. The cope core can also be manufactured from highly eutectic materials (see Chap. 12).

**Fig. 78. Feeders (Williams type) with simple and double spherical domes.**

---

1. **Without core.** A sinkhole cavity is formed from the bottom and filled to the runner.

2. **With a pencil-shaped core made of old sand or graphite.** One way in which graphite acts is by lowering the melting point of the steel by carburization, so that the pressure of the atmosphere can be brought to bear on metal which remains liquid for a longer time.

3. **With a short, acute-angled penetration core.**

4. **5. Stereoscopic graphite pencil cores at various levels show that the atmospheric pressure can act against the force of gravity.**

The reliability of open feeder heads is increased by penetration cores of this type.
Using ordinary antispattering powders, the radiation of heat from open and blind feeder heads is practically the same (the insulating effect of the sand in blind feeders is often overestimated).

As a solidified skin forms around the feeder shortly after casting (Fig. 79), a way must be opened up from the atmosphere into the liquid interior by means of permeable cores. This also applies to "blind" feeder heads. Instead of the core a sharp sand fillet can also serve the same purpose; however, this is often unreliable, as it can break away due to insufficient sand strength or slow release moulding; the fragments of sand can even enter the casting. Perforation cores should be permeable to gases, and acute-angled cores are to be preferred; because of the high heat concentration at the apex, the steel remains liquid for a long period (Fig. 80).
Should small feeder blocks (under 50 mm diameter) be used, the metal must not be too cold, otherwise they will not feed. The size of this appendage (Fig. 81) is less than required and the penetration core cannot reach hot metal and thus remains ineffective, so that shrinkage cavities are inevitable.

Porosity is sometimes produced when using fluid feeders, the cause of which is usually wrongly interpreted. It may actually be due to incomplete filling (Figs. 82a-b). The caster is deceived by a spray of metal into thinking that the mould is full, pouring is stopped prematurely, and shrinkage cavities are formed. No spraying effect is observed as long as the total cross-section of all the whiskers is larger than that of the downgate. This phenomenon has nothing to do with the ferrostatic pressure or with a suction effect exerted by the whiskers.

The calculated casting yield using fluid feeders placed at the side is often less than when open feeders are placed on top, because of the extra weight of the ingate. As overfilling is impossible with blind feeders, however (Fig. 83), they are often more economical for that reason. This, and the feeding possibilities inherent in a low...
centres of gravity, are the main advantages of the blind feeder.

It should be noted in the case of low-situated blind feeders that open feeders with a higher metal surface will help the low-positioned feeders to supply metal as long as a liquid connection remains between the upper and lower feeders (Fig. 84). Only after this connection has solidified does the blind feeder act independently. This means that about 65 to 75 per cent of the weight of the blind feeder must be added to the casting weight when calculating the size of this feeder, and only then must the uppermost, open feeders be determined.

The following basic rule applies to this type of casting; in calculating the feeders, always commence at the lowest point and proceed upwards.

5.4. Behaviour of the Feeder Head during Solidification

IMPORTANT FOR PRACTICE

Ideally, open topped feeder heads show a continuous shrinkage cavity in the form of a hollow cone, the generated surface of which is curved (Figs. 85 a-b). The line of curvature is practically a parabola, and is theoretically a logarithmic curve (see also Figs. 941 and 342).

The cavity is formed by evacuation of the feeder by the casting, resulting in a substantial reduction in the initial volume of the feeder. On the other hand, the heat radiating surface of the feeder is increased by the formation of the parabolic conical surface. If two cylinders of the same size are placed one above the other, as in Fig. 86, the modulus of the upper cylinder will decrease during solidification, due to a decrease in volume and an increase in surface area, i.e., it will solidify earlier than the casting (in this case the lower cylinder). The decrease in
the modulus during solidification amounts to about 17 per cent of the original modulus. The modulus of the feeder at the beginning must therefore be about 1.2 times that of the casting, for the modulus of the feeder and casting to be equal after solidification is completed. This is the basis of the safety factor $f = 1.2$, which has been mentioned several times already (cf. Chapter 4, Sections 1 and 2 and Chapter 5, Section 6).

The expression "compensating factor" would be better, but the expression "safety factor" will be retained also, as it is in common use.

The shrinkage cone should not reach as far as the upper edge of the casting, but for safety the maximum permissible depth of the shrinkage cavity may be limited to $d = 0.8H$ (where $H$ is the height of the feeder). Parabolic shrinkage cones of this depth always occupy 14 per cent of the original feeder volume.

From this can also be calculated, from the contraction of the metal in question, the maximum volume or weight of casting that can be supplied from the feeder head. This volume should correspond to the capacity of the feeding range with economically designed feeders.

It is sometimes asserted in the literature that a feeder dimensioned to give the correct modulus will "automatically" contain enough liquid material to feed the casting. This is not always true by any means because of the 14 per cent limit due to a parabolic shrinkage cavity; the practical consequences will now be explained.

Massive bodies require less feeder metal than plate-shaped castings having the same modulus, in contradiction to the general opinion and to the "first impression."

Figure 87 and the attached table show that the shrinkage requirements of a plate can amount to several times those of a cube with the same modulus.

5.5. Shrinkage

By this is meant the reduction in volume of the metal in the liquid state up to the completion of solidification.

The reduction of volume in the solid state is known as contraction.

![Fig. 86: Changes in two cylindrical castings of the same size during solidification.](image)

![Fig. 87: Comparison of volumes and shrinkage requirements of a plate and a cube of the same modulus ($M = \frac{3}{2}$ cm). Assumed shrinkage $f = 4.5\%$](image)

<table>
<thead>
<tr>
<th></th>
<th>Volume, cm$^3$</th>
<th>Feeding requirements, cm$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate without</td>
<td>49,000</td>
<td>3200</td>
</tr>
<tr>
<td>end zone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plate with end</td>
<td>444,000</td>
<td>6500</td>
</tr>
<tr>
<td>zone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cube</td>
<td>27,000</td>
<td>1220</td>
</tr>
</tbody>
</table>

The more intensive the shrinkage, the more rapidly the metal is drawn from the feeder and the more quickly the 14 per cent limit is reached. The temperature-dependent volume changes of the iron-carbon alloys were investigated by Benedicks, Ericsson, Ericson, Kohany and others$^{46-47}$; Fig. 88 shows the results. Figures 89 and 90 are derived from these results, Fig. 90 giving the

![Fig. 88: Variations of specific volume with temperature of iron-carbon alloys (after Benedicks, Ericsson, Ericson and Kohany).](image)
Fig. 89. Variations in the volume of iron-carbon alloys with temperature.

According to Stein, these values are to be considered only as tendencies.

Fig. 90a. Influence of carbon content and casting temperature on the tendency of steels to form shrinkage cavities. The values were determined on a spherical sample (70 mm diam.), the cavity volumes being measured with low surface tension water (after Stein).

shrinkage in per cent. The shrinkage of unalloyed steels is accordingly less than is normally assumed. Stein also made corresponding experiments (Figs. 91a–b). The results in this case show trends only; nevertheless they agree fairly well in order of magnitude with the data published by the other authors. Due to the critical 14 per cent limit and to the small amount of shrinkage, small fluctuations are significant. For this reason the influence of other alloying elements was also investigated, unfortunately only at 1000°C (Fig. 92). However, if the

Fig. 91a. Test piece for determining shrinkage volume (after Stein).

Fig. 92. Change in the specific volume of iron due to the presence of alloying elements at 1000°C.

Calculation of shrinkage factor (values from table 6).

If the specific volume is

$$ V = V_0 - \Delta V $$

$$ \Delta V = \frac{100 \times \Delta T}{T_0 + \Delta T} $$

$$ T_0 = 1000 \pm 10 \text{°C} $$
same relationships are assumed to be approximately true for the entire temperature range, data of general validity can be derived for other temperatures (Table 6).

**Table 6. Change in the Shrinkage of Steel Due to Alloying Elements**

1. Change in shrinkage at 1600°C, after Benedicks, Ericsson et al., [10].

<table>
<thead>
<tr>
<th>Alloying element</th>
<th>Change in percentage shrinkage per % alloy content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tungsten</td>
<td>-0.33</td>
</tr>
<tr>
<td>Nickel</td>
<td>-0.034</td>
</tr>
<tr>
<td>Manganese</td>
<td>-0.028</td>
</tr>
<tr>
<td>Chromium</td>
<td>-0.12</td>
</tr>
<tr>
<td>Silicon</td>
<td>+1.65</td>
</tr>
<tr>
<td>Aluminium</td>
<td>+1.70</td>
</tr>
</tbody>
</table>

2. Change in shrinkage at temperatures below 1600°C. Approximately linear relationships should be assumed between shrinkage factor and temperature, i.e., the above table is also valid at low temperatures. The shrinkage factors for carbon must be taken from Fig. 09.

3. Example: manganese steel, casting temp. about 1450°C.

<table>
<thead>
<tr>
<th>Element</th>
<th>%</th>
<th>Shrinkage factor</th>
<th>% Alloy content</th>
<th>Shrinkage %</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>1.5</td>
<td>from Fig. 09-5</td>
<td>×15</td>
<td>+5</td>
</tr>
<tr>
<td>Mn</td>
<td>15</td>
<td>+0.0368</td>
<td>×15</td>
<td>-0.38</td>
</tr>
<tr>
<td>Si</td>
<td>0.3</td>
<td>+0.033</td>
<td>×0.3</td>
<td>-0.33</td>
</tr>
<tr>
<td>Cr</td>
<td>1.25</td>
<td>+0.012</td>
<td>×1.25</td>
<td>-0.12</td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td>+0.31</td>
<td>+0.5</td>
<td></td>
</tr>
</tbody>
</table>

4. Safety. As 2. is based on an assumption, the result should be rounded off to the nearest five-tenths, i.e., 0.31 → 0.5.

**5.6. Calculations Giving the Shrinkage Cavity Characteristics of the Best Form of Feeder Head and the Compensating Factor**

(Even if this section is omitted, the remaining sections on feeder calculation can be understood.)

Instead of taking the logarithmic curvature of the shrinkage cavity in the feeder head, a parabolic form can be assumed for practical purposes, corresponding to the equation:

\[ y = \frac{x^2}{2p} \]  

(14)

where \( p \) is the parameter. By rotating around the axis \( z = a \) (Fig. 93) a parabolic cone is generated, having a depth

\[ d = \frac{p^2}{2} \]

(15)

\( R \) is also the radius of the feeder head. Volume and parameter can now be calculated. We have:

\[ V_{sc} = 2\pi \int (R - x) y \, dx - 2\pi \int_{0}^{R} (R - x) \frac{x^4}{p} \, dx \]

\[ = \frac{\pi}{p} \left( \frac{R^4}{5} - \frac{R^5}{3} \right) \] and

\[ V_{sc} = \frac{\pi R^3}{12} \] \( \text{or} \) \( p = \frac{R^3}{12 V_{sc}} \)  

(16)

where \( V_{sc} \) is the volume of the parabolic shrinkage core.

The surface area \( H \) of the cone is:

\[ H = 2\pi \int_{0}^{R} (R - x) \sqrt{1 + y^2} \, dx \]

\[ = \frac{x^2}{p} \]

\[ H = 2\pi R \int_{0}^{R} \sqrt{1 + \frac{x^2}{p^2}} \times dx - 2\pi \int_{0}^{R} \sqrt{1 + \frac{x^4}{p^2}} \times dx \]

\[ = \frac{2\pi R}{p} \int_{0}^{R} \sqrt{p^2 + x^2} \times dx - \frac{2\pi}{p} \times \left[ \frac{x^2}{2} + \frac{x^4}{4} \right] \]

\[ = \frac{2\pi R}{2} \sqrt{p^2 + R^2} + \frac{p^2}{2} \ln \left( R + \sqrt{p^2 + R^2} \right) - \frac{p^2}{2} \ln \left( R + \frac{p}{R} \sqrt{R^2 + p^2} \right) - \left[ \frac{p^2}{2} \right] \]

(17)

Instead of this unwieldy equation, individual curves can also be divided out into sections and determined planimetrically, or the arc length is measured and the trapezoidal sections calculated.

Hence only the model cases for the radii \( R = 10 \) and \( R = 14.2 \) were calculated (cf. Table 7) and there were transposed to other radii in accordance with the law of geometrical similarity.
Table 7a.

Feeder values before commencement of shrinkage

\[ V_F = 6280 \text{ cm}^3 \]

- Generated surface \( A = D; \)
- \( H = 1280 \text{ cm}^2; \)
- Cooling surface = 1491 cm²
- Modulus = 3.05 cm

<table>
<thead>
<tr>
<th>Depth of cavity ( t ) cm</th>
<th>8</th>
<th>12</th>
<th>16</th>
<th>20</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vol. of cavity ( V_{SC} ) cm³</td>
<td>426</td>
<td>542</td>
<td>852</td>
<td>1070</td>
<td></td>
</tr>
<tr>
<td>Generated surface of the cavity cone ( H ) cm²</td>
<td>379</td>
<td>461</td>
<td>534</td>
<td>593</td>
<td></td>
</tr>
<tr>
<td>Steel volume in the feeder at the end of solidification ( V_E ) cm³</td>
<td>5354</td>
<td>5538</td>
<td>5428</td>
<td>5216</td>
<td></td>
</tr>
<tr>
<td>Cooling surface on solidification ( A + H ) cm²</td>
<td>1455</td>
<td>1750</td>
<td>1570</td>
<td>1180</td>
<td></td>
</tr>
</tbody>
</table>

- Modulus on solidification \( \frac{V_E}{A + H} \) cm
- Depth of cavity \( t_H \) cm
  - 0.4
- Vol. of cavity \( V_{SC}/V_F \)
  - 0.07
- Steel volume on solidification \( V_E/V_F \)
  - 0.93
| Modulus \( M_E/V_F \) | 0.895 | 0.82 | 0.77 | 0.70 |

Table 7b.

Feeder values before commencement of shrinkage

\[ V_F = 9429 \text{ cm}^3 \]

- Generated surface \( A = 1920 \text{ cm}^2; \)
- Cooling surface = 2234 cm²
- Initial modulus = 4.21 cm

<table>
<thead>
<tr>
<th>Depth of cavity ( t ) cm</th>
<th>8</th>
<th>12</th>
<th>16</th>
<th>20</th>
<th>25</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vol. of cavity ( V_{SC} ) cm³</td>
<td>425</td>
<td>642</td>
<td>852</td>
<td>1070</td>
<td>1336</td>
<td>1686</td>
</tr>
<tr>
<td>Generated surface of the cavity cone ( H ) cm²</td>
<td>379</td>
<td>464</td>
<td>524</td>
<td>591</td>
<td>656</td>
<td>800</td>
</tr>
<tr>
<td>Steel volume in the feeder at the end of solidification ( V_E ) cm³</td>
<td>8994</td>
<td>8778</td>
<td>8568</td>
<td>8259</td>
<td>8084</td>
<td>7814</td>
</tr>
<tr>
<td>Cooling surface on solidification ( A + H ) cm²</td>
<td>2205</td>
<td>2370</td>
<td>2430</td>
<td>2420</td>
<td>2620</td>
<td>2700</td>
</tr>
</tbody>
</table>

- Modulus on solidification \( \frac{V_E}{A + H} \) cm
- Depth of cavity \( t_H \) cm
  - 0.266
- Vol. of cavity \( V_{SC}/V_F \)
  - 0.045
- Steel volume on solidification \( V_E/V_F \)
  - 0.955
| Modulus \( M_E/M_F \) | 0.92 | 0.88 | 0.84 | 0.785 | 0.735 | 0.685 |

Table 7c.

Feeder values before commencement of shrinkage \( V_F = 5346 \text{ cm}^3 \)

- Cooling surface = 1880 cm²
- Modulus = 4.44 cm

The depth of the shrinkage cavity can only be calculated approximately due to the spherical cap. The cavity measures at the most 17% of the initial volume, reducing to 14% if a safety limit is incorporated.

| Vol. of cavity \( V_{SC}/V_F \) | 0.02 | 0.05 | 0.10 | 0.13 | 0.17 |
| Steel volume in the feeder at the end of solidification | 0.58 | 0.91 | 0.95 | 0.87 | 0.83 |
| Modulus at the end of solidification cm | 4.15 | 4.21 | 4.60 | 3.86 | 3.70 |
| Modulus in fractions of the initial modulus \( M_E/M_F \) | 0.895 | 0.99 | 0.99 | 0.87 | 0.83 |
| Factor \( f = \frac{M_F}{M_E} \) | 1.04 | 1.05 | 1.11 | 1.15 | 1.2 |

The main part of the cavity volume lies near the base of the cone. An obvious step is to increase the size of this base and so reduce the depth \( d \) of the cavity for a given cavity volume. Not only cylindrical but also conical or hemispherical feeders, the exterior shape of which is adapted to the type of cavity, will be investigated.
### Table 7d.

Calculations Giving the Shrinkage Cavity Characteristics

<table>
<thead>
<tr>
<th>Depth of cavity ( t ) (cm)</th>
<th>5</th>
<th>7.5</th>
<th>10</th>
<th>14.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vol. of cavity ( V_{sc} ) (cm³)</td>
<td>528</td>
<td>704</td>
<td>1056</td>
<td>1500</td>
</tr>
<tr>
<td>Generated surface of the cavity cone ( H ) (cm²)</td>
<td>960</td>
<td>494</td>
<td>738</td>
<td>845</td>
</tr>
<tr>
<td>Steel volume in the feeder of solidification ( V_F ) (cm³)</td>
<td>54.24</td>
<td>5188</td>
<td>4924</td>
<td>4480</td>
</tr>
<tr>
<td>Cooling surface on solidification ( A + H ) (cm²)</td>
<td>17.53</td>
<td>1847</td>
<td>1891</td>
<td>1968</td>
</tr>
<tr>
<td>Modulus on solidification ( M_E )</td>
<td>3.11</td>
<td>2.91</td>
<td>2.61</td>
<td>2.28</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth of cavity ( h ) (cm)</th>
<th>0.35</th>
<th>0.53</th>
<th>0.70</th>
<th>0.84</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vol. of cavity ( V_{sc} )</td>
<td>0.088</td>
<td>0.139</td>
<td>0.18</td>
<td>0.25</td>
</tr>
<tr>
<td>Steel volume on solidification ( V_E/V_F )</td>
<td>0.012</td>
<td>0.037</td>
<td>0.08</td>
<td>0.075</td>
</tr>
<tr>
<td>Modulus ( M_E/M_F )</td>
<td>0.93</td>
<td>0.86</td>
<td>0.78</td>
<td>0.68</td>
</tr>
</tbody>
</table>

### Table 7c.

Assumptions: \( d \approx 0.57 D \)

\[ D = 1.46 \overline{D} \]

\[ R = 1.45 \overline{R} \]

\[ V_F = \frac{4}{12} \pi r^4 \]

\[ t = 0.64d = 1.2R = \frac{r^2}{3} \]

\[ p = \frac{r^2}{2} \]

\[ V_F = \frac{4}{12} \pi r^4 \cdot \frac{2}{3} \]

\[ e = \frac{r^2}{6} \]

\[ V_{sph} = 2.663^{p} \]

\[ V_{sph} = 2.06 \]

\[ V = 0.266 \]

\[ V_{sph} = 0.197 \cdot V \approx 0.2 \cdot V \text{ or } \approx 20\% \text{ of the solid sphere} \]

### Fig. 94. Change in the characteristic values of various shapes of feeder using approximate and accurate methods of calculation.

#### Feeder shape

- **Characteristics values in relationship to the modulus of the feeder**

<table>
<thead>
<tr>
<th>Feeder shape</th>
<th>Characteristic values</th>
<th>accurate</th>
<th>approximate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( V_F = 2.09 R^n = 95 (M_F)^3 )</td>
<td>( V_F = 2.09 R^n = 156 (M_F)^3 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( A_F = 5.07 \pi )</td>
<td>( A_F = 6.82 \pi )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( M_E = 0.49 R = 0.214 D )</td>
<td>( M_E = 0.496 D = \frac{D}{3} )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( R = 2.5 M_F )</td>
<td>( R = 3.31 M_F )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( R^n = 12.5 (M_F)^3 )</td>
<td>( R^n = 37 (M_F)^3 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( V_F = 2.09 R^n = 122 (M_F)^3 )</td>
<td>( V_F = 3.75 R^n = 179 (M_F)^3 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( A_F = 7.07 \pi )</td>
<td>( A_F = 8.87 \pi )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( M_E = 0.492 R = 0.214 D )</td>
<td>( M_E = 0.372 R = 0.187 D )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( R = 2.33 M_F )</td>
<td>( R = 2.5 M_F )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( R^n = 12.5 (M_F)^3 )</td>
<td>( R^n = 15 (M_F)^3 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( V_F = 2.09 R^n = 156 (M_F)^3 )</td>
<td>( V_F = 5.54 R^n = 156 (M_F)^3 )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( A_F = 5.07 \pi )</td>
<td>( A_F = 7.37 \pi )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( M_E = 0.44 R = 0.222 D )</td>
<td>( M_E = 0.378 R = 0.189 D )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( R = 2.25 M_F )</td>
<td>( R = 2.65 M_F )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>( R^n = 11.7 (M_F)^3 )</td>
<td>( R^n = 10.7 (M_F)^3 )</td>
<td></td>
</tr>
</tbody>
</table>
It is an advantage for comparison purposes to give all feeder dimensions in connection with the modulus, which of course represents a length. The calculations must first of all be accurate, i.e. the feeder/casting interface, on which no cooling occurs, must not be included in the determination of the modulus. Figure 94 gives characteristic values for various forms of feeder, using both approximate and exact calculations, and shows the existence of differences.

Fig. 93. Modulus and shrinkage cavity volume as a function of the depth of the cavity in the feeder. Applies to cylindrical feeders of the shapes $H = D$ and $H = 1.5D$.

These feeder types were calculated in Tables 7a-e as model cases, and the results converted to numbers having general validity. Figures 95-97 show the behaviour of the feeder when forming shrinkage cavities. The volume of the cavity increases in direct proportion to its depth, and the feeder modulus decreases linearly, which simplifies the subsequent calculations. The safety ("compensating") factor can be derived directly; it varies according to the depth of the cavity. The practical calculation may be based, not on the final modulus at the completion of solidification, but on the mean of the initial and final modulus. On true safety grounds, however, the requirement is laid down that the feeder modulus at the completion of solidification shall coincide with the modulus of the casting.

To the extent that the interface feeder/casting is not allowed for (always in the practical rapid calculation) so that it is included as a cooling surface in the calculation (approximate method), the result is a displacement of the factor $f$, the size of which is a function of the shape of the casting. Various factors are compared in Table 8.

In most castings this factor then lags by about 0.1, but becomes identical with massive parts. As, however, the degree of utilization of the feeder is low on massive parts, i.e. the depth of the shrinkage cavity is less and the 14 per cent limit is not reached as quickly, the factor is less in itself in such parts (cf. also Fig. 87). Consequently, the factor $f = 1.2$ can be used throughout in the approximate method. In the present section the accurate method of calculation will be used, so as to obtain exact values; but the approximate method will be employed for the remainder of the book.
### Table 8: Change in the Equalization Factor When the Approximate Calculation Is Compared with the Accurate One

<table>
<thead>
<tr>
<th>Calculation</th>
<th>accurate (allowing for feed/extra interface)</th>
<th>approximate (no allowance made for feed/extra interface)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piece (with feeder zone only)</td>
<td>( f = 1.29 )</td>
<td>( f = 1.22 )</td>
</tr>
<tr>
<td>Bar 1:1, with feeder and end zone</td>
<td>( f = 1.33 )</td>
<td>( f = 1.23 )</td>
</tr>
<tr>
<td>Bar 1:1, with feeder and end zone</td>
<td>( f = 1.28 )</td>
<td>( f = 1.19 )</td>
</tr>
<tr>
<td>Cube</td>
<td>( f = 1.17 )</td>
<td>( f = 1.17 )</td>
</tr>
</tbody>
</table>

The \( f \)-values for approximate calculation are determined by back-calculation, i.e., the feeder dimensions are determined first by the accurate method, then the approximate modulus of the feeder determined in this way is calculated, and divided by the approximate casting modulus.

Nicholas introduced for the first time the feeder calculation using the factor \( f = 1.2 \) (but without the mathematical-physical basis that is given here) which enabled theoretically accurate (although practically unnecessary) calculations to be made. As the change in surface area of the feeder head is also taken into account, the method is more accurate than the calculating procedure given by Namur which only allowed for the changes in volume. As Namur's method is also complicated, the simpler method developed by Nicholas will be used for calculation.

Figure 98 shows the influence of the shrinkage \( S \) (in per cent) on the depth of the cavity \( d \). We have:

\[
V_{sc} = \frac{V_0}{100} (V_{casting} + V_{feed}) \\
V_{casting} = \frac{100 V_{sc} - S \cdot V_p}{S}
\]  

(18)

According to Figs. 95, 96 and 97 the following is true for cylindrical feeders:

\[ V_{sc} = 0.14 V_p \]  

(19)

and the max:

\[ V_{max} = V_p \cdot \frac{44 - S}{S} \]  

(20)

for hemispherical feeders:

\[ V_{sc} = 0.20 V_p \]  

(21)

\[ V_{max} = V_p \cdot \frac{20 - S}{S} \]  

(22)

Hence the feeder volume and the maximum volume of casting \( V_{max} \) which can be fed (not to be confused with the feeding range) are related via the shrinkage \( S \) (Figs. 99a-b). In the feeder tables 9-49, therefore, the maximum volume which can be fed is entered for each feeder for different amounts of shrinkage.
Table 9. CYLINDRICAL FEEDER HEAD \( H = D \)

<table>
<thead>
<tr>
<th>( M_f )</th>
<th>( D^a )</th>
<th>( V )</th>
<th>( \nu )</th>
<th>( \nu )</th>
<th>( V )</th>
<th>( \nu )</th>
<th>( \nu )</th>
<th>( \nu )</th>
<th>( \nu )</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm</td>
<td>mm</td>
<td>litres</td>
<td>m. tons</td>
<td>( \nu )</td>
<td>( \nu )</td>
<td>( \nu )</td>
<td>( \nu )</td>
<td>( \nu )</td>
<td>( \nu )</td>
</tr>
<tr>
<td>0.5</td>
<td>30</td>
<td>22</td>
<td>0.15</td>
<td>55</td>
<td>0.43</td>
<td>45</td>
<td>0.32</td>
<td>36</td>
<td>0.24</td>
</tr>
<tr>
<td>0.6</td>
<td>36</td>
<td>37</td>
<td>0.26</td>
<td>63</td>
<td>0.73</td>
<td>67</td>
<td>0.35</td>
<td>52</td>
<td>0.40</td>
</tr>
<tr>
<td>0.7</td>
<td>42</td>
<td>57</td>
<td>0.52</td>
<td>143</td>
<td>1.12</td>
<td>104</td>
<td>0.82</td>
<td>77</td>
<td>0.60</td>
</tr>
<tr>
<td>0.8</td>
<td>48</td>
<td>86</td>
<td>0.90</td>
<td>215</td>
<td>1.68</td>
<td>155</td>
<td>1.20</td>
<td>116</td>
<td>0.91</td>
</tr>
<tr>
<td>0.9</td>
<td>54</td>
<td>123</td>
<td>0.84</td>
<td>318</td>
<td>2.50</td>
<td>220</td>
<td>1.82</td>
<td>165</td>
<td>1.30</td>
</tr>
<tr>
<td>1.0</td>
<td>60</td>
<td>169</td>
<td>1.15</td>
<td>422</td>
<td>3.30</td>
<td>305</td>
<td>2.40</td>
<td>228</td>
<td>1.80</td>
</tr>
<tr>
<td>1.1</td>
<td>66</td>
<td>225</td>
<td>1.55</td>
<td>562</td>
<td>4.40</td>
<td>403</td>
<td>3.17</td>
<td>339</td>
<td>2.63</td>
</tr>
<tr>
<td>1.2</td>
<td>72</td>
<td>290</td>
<td>1.97</td>
<td>735</td>
<td>5.70</td>
<td>526</td>
<td>4.10</td>
<td>392</td>
<td>3.24</td>
</tr>
<tr>
<td>1.3</td>
<td>78</td>
<td>350</td>
<td>2.12</td>
<td>925</td>
<td>7.20</td>
<td>670</td>
<td>5.25</td>
<td>550</td>
<td>4.20</td>
</tr>
<tr>
<td>1.4</td>
<td>84</td>
<td>460</td>
<td>3.12</td>
<td>1.2</td>
<td>5.40</td>
<td>830</td>
<td>6.30</td>
<td>628</td>
<td>4.90</td>
</tr>
<tr>
<td>1.5</td>
<td>90</td>
<td>570</td>
<td>4.13</td>
<td>1.4</td>
<td>6.19</td>
<td>1.0</td>
<td>7.80</td>
<td>779</td>
<td>6.00</td>
</tr>
<tr>
<td>1.6</td>
<td>96</td>
<td>680</td>
<td>5.14</td>
<td>1.6</td>
<td>7.14</td>
<td>1.3</td>
<td>10.20</td>
<td>940</td>
<td>7.20</td>
</tr>
<tr>
<td>1.7</td>
<td>112</td>
<td>820</td>
<td>5.60</td>
<td>2.1</td>
<td>11.4</td>
<td>1.3</td>
<td>14.70</td>
<td>1.1</td>
<td>13.02</td>
</tr>
<tr>
<td>1.8</td>
<td>128</td>
<td>980</td>
<td>6.20</td>
<td>2.5</td>
<td>14.5</td>
<td>1.3</td>
<td>18.40</td>
<td>1.3</td>
<td>19.04</td>
</tr>
<tr>
<td>1.9</td>
<td>144</td>
<td>1140</td>
<td>7.20</td>
<td>3.0</td>
<td>20.1</td>
<td>1.8</td>
<td>22.70</td>
<td>1.6</td>
<td>22.70</td>
</tr>
<tr>
<td>2.0</td>
<td>160</td>
<td>1300</td>
<td>8.20</td>
<td>3.5</td>
<td>26.0</td>
<td>2.5</td>
<td>27.10</td>
<td>1.9</td>
<td>28.70</td>
</tr>
<tr>
<td>2.1</td>
<td>176</td>
<td>1460</td>
<td>9.20</td>
<td>4.0</td>
<td>32.0</td>
<td>3.0</td>
<td>32.50</td>
<td>2.2</td>
<td>34.70</td>
</tr>
<tr>
<td>2.2</td>
<td>192</td>
<td>1620</td>
<td>10.30</td>
<td>4.5</td>
<td>38.0</td>
<td>3.5</td>
<td>38.50</td>
<td>2.5</td>
<td>40.70</td>
</tr>
<tr>
<td>2.3</td>
<td>208</td>
<td>1780</td>
<td>11.30</td>
<td>5.0</td>
<td>44.0</td>
<td>4.0</td>
<td>44.50</td>
<td>2.8</td>
<td>42.70</td>
</tr>
<tr>
<td>2.4</td>
<td>224</td>
<td>1940</td>
<td>12.30</td>
<td>5.5</td>
<td>50.0</td>
<td>4.5</td>
<td>50.50</td>
<td>3.1</td>
<td>52.70</td>
</tr>
<tr>
<td>2.5</td>
<td>240</td>
<td>2100</td>
<td>13.30</td>
<td>6.0</td>
<td>56.0</td>
<td>5.0</td>
<td>56.50</td>
<td>3.4</td>
<td>54.70</td>
</tr>
<tr>
<td>2.6</td>
<td>256</td>
<td>2260</td>
<td>14.30</td>
<td>6.5</td>
<td>62.0</td>
<td>5.5</td>
<td>62.50</td>
<td>3.7</td>
<td>59.70</td>
</tr>
<tr>
<td>2.7</td>
<td>272</td>
<td>2420</td>
<td>15.30</td>
<td>7.0</td>
<td>68.0</td>
<td>6.0</td>
<td>68.50</td>
<td>4.0</td>
<td>66.70</td>
</tr>
<tr>
<td>2.8</td>
<td>288</td>
<td>2580</td>
<td>16.30</td>
<td>7.5</td>
<td>74.0</td>
<td>6.5</td>
<td>74.50</td>
<td>4.3</td>
<td>73.70</td>
</tr>
<tr>
<td>2.9</td>
<td>304</td>
<td>2740</td>
<td>17.30</td>
<td>8.0</td>
<td>80.0</td>
<td>7.0</td>
<td>80.50</td>
<td>4.6</td>
<td>82.70</td>
</tr>
<tr>
<td>3.0</td>
<td>320</td>
<td>2900</td>
<td>18.30</td>
<td>8.5</td>
<td>86.0</td>
<td>7.5</td>
<td>86.50</td>
<td>4.9</td>
<td>84.70</td>
</tr>
</tbody>
</table>

**Note:** The table provides the max. loadable volume of casting \( V \) (liters) for a shrinkage of 4%, 5%, and 6%, respectively.
### Table 16. Cylindrical Feeder Head $H = 1.5D$

<table>
<thead>
<tr>
<th>$M_r$</th>
<th>$D_r$</th>
<th>$H$</th>
<th>$V$</th>
<th>$w^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm</td>
<td>mm</td>
<td>mm</td>
<td>m</td>
<td>litres</td>
</tr>
<tr>
<td>0.1</td>
<td>27</td>
<td>40</td>
<td>24</td>
<td>0.17</td>
</tr>
<tr>
<td>0.6</td>
<td>48</td>
<td>60</td>
<td>40</td>
<td>0.27</td>
</tr>
<tr>
<td>0.8</td>
<td>57</td>
<td>67</td>
<td>63</td>
<td>0.42</td>
</tr>
<tr>
<td>0.8</td>
<td>63</td>
<td>69</td>
<td>65</td>
<td>0.53</td>
</tr>
<tr>
<td>0.9</td>
<td>72</td>
<td>78</td>
<td>83</td>
<td>0.63</td>
</tr>
<tr>
<td>1.0</td>
<td>81</td>
<td>89</td>
<td>100</td>
<td>0.82</td>
</tr>
<tr>
<td>1.1</td>
<td>90</td>
<td>98</td>
<td>110</td>
<td>0.63</td>
</tr>
<tr>
<td>1.2</td>
<td>96</td>
<td>104</td>
<td>115</td>
<td>0.24</td>
</tr>
<tr>
<td>1.3</td>
<td>105</td>
<td>120</td>
<td>125</td>
<td>0.09</td>
</tr>
<tr>
<td>1.4</td>
<td>115</td>
<td>130</td>
<td>135</td>
<td>0.05</td>
</tr>
<tr>
<td>1.6</td>
<td>130</td>
<td>140</td>
<td>145</td>
<td>0.03</td>
</tr>
</tbody>
</table>

**Max. feedable volume of coving $V$ (ut $w^*$) for a shrinkage of:**

<table>
<thead>
<tr>
<th>$V$</th>
<th>$w^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm$^3$, l</td>
<td>kg, t</td>
</tr>
<tr>
<td>0%</td>
<td>0.04</td>
</tr>
<tr>
<td>10%</td>
<td>0.10</td>
</tr>
<tr>
<td>30%</td>
<td>0.47</td>
</tr>
<tr>
<td>50%</td>
<td>0.78</td>
</tr>
<tr>
<td>20%</td>
<td>0.10</td>
</tr>
<tr>
<td>60%</td>
<td>0.34</td>
</tr>
<tr>
<td>30%</td>
<td>0.14</td>
</tr>
<tr>
<td>50%</td>
<td>0.43</td>
</tr>
<tr>
<td>20%</td>
<td>0.10</td>
</tr>
<tr>
<td>60%</td>
<td>0.43</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Max. feedable volume of coving $V$ (ut $w^*$) for a shrinkage of:</th>
</tr>
</thead>
<tbody>
<tr>
<td>4%</td>
</tr>
<tr>
<td>5%</td>
</tr>
<tr>
<td>6%</td>
</tr>
<tr>
<td>7%</td>
</tr>
<tr>
<td>$V$ cm$^3$, l</td>
</tr>
<tr>
<td>0%</td>
</tr>
<tr>
<td>10%</td>
</tr>
<tr>
<td>30%</td>
</tr>
<tr>
<td>50%</td>
</tr>
<tr>
<td>20%</td>
</tr>
<tr>
<td>60%</td>
</tr>
<tr>
<td>30%</td>
</tr>
<tr>
<td>50%</td>
</tr>
<tr>
<td>20%</td>
</tr>
<tr>
<td>60%</td>
</tr>
</tbody>
</table>
### Feeder Heads

#### Table 11. OVAL FEEDER HEAD

<table>
<thead>
<tr>
<th>$M_{p}$</th>
<th>$a$</th>
<th>$b$</th>
<th>$c$</th>
<th>$V$</th>
<th>$W$</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm</td>
<td>mm</td>
<td>mm</td>
<td>mm</td>
<td>cm³/litres</td>
<td>kg/ton</td>
</tr>
<tr>
<td>---------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-------------</td>
<td>---------</td>
</tr>
<tr>
<td>0.5</td>
<td>24</td>
<td>36</td>
<td>30</td>
<td>24</td>
<td>0.16</td>
</tr>
<tr>
<td>0.6</td>
<td>29</td>
<td>44</td>
<td>40</td>
<td>40</td>
<td>0.27</td>
</tr>
<tr>
<td>0.7</td>
<td>34</td>
<td>51</td>
<td>45</td>
<td>52</td>
<td>0.42</td>
</tr>
<tr>
<td>0.8</td>
<td>39</td>
<td>59</td>
<td>59</td>
<td>53</td>
<td>0.63</td>
</tr>
<tr>
<td>0.9</td>
<td>44</td>
<td>66</td>
<td>65</td>
<td>53</td>
<td>0.90</td>
</tr>
<tr>
<td>1.0</td>
<td>49</td>
<td>74</td>
<td>71</td>
<td>71</td>
<td>1.25</td>
</tr>
<tr>
<td>1.1</td>
<td>54</td>
<td>81</td>
<td>77</td>
<td>77</td>
<td>1.45</td>
</tr>
<tr>
<td>1.2</td>
<td>59</td>
<td>88</td>
<td>83</td>
<td>83</td>
<td>1.65</td>
</tr>
<tr>
<td>1.3</td>
<td>65</td>
<td>95</td>
<td>90</td>
<td>90</td>
<td>1.87</td>
</tr>
<tr>
<td>1.4</td>
<td>72</td>
<td>102</td>
<td>95</td>
<td>95</td>
<td>2.04</td>
</tr>
<tr>
<td>1.5</td>
<td>78</td>
<td>107</td>
<td>99</td>
<td>99</td>
<td>2.21</td>
</tr>
<tr>
<td>1.6</td>
<td>84</td>
<td>114</td>
<td>103</td>
<td>103</td>
<td>2.38</td>
</tr>
<tr>
<td>1.7</td>
<td>91</td>
<td>120</td>
<td>108</td>
<td>108</td>
<td>2.55</td>
</tr>
<tr>
<td>1.8</td>
<td>98</td>
<td>126</td>
<td>113</td>
<td>113</td>
<td>2.71</td>
</tr>
<tr>
<td>1.9</td>
<td>105</td>
<td>132</td>
<td>118</td>
<td>118</td>
<td>2.88</td>
</tr>
<tr>
<td>2.0</td>
<td>112</td>
<td>138</td>
<td>123</td>
<td>123</td>
<td>3.05</td>
</tr>
</tbody>
</table>

**Max. fetchable volume of cutting $V$ (wt $W$) for a shrinkage $c$:**

<table>
<thead>
<tr>
<th>$\alpha$%</th>
<th>$\beta$%</th>
<th>$\gamma$%</th>
<th>$\delta$%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V'$ cm³/l</td>
<td>$W'$ kg/ton</td>
<td>$V''$ cm³/l</td>
<td>$W''$ kg/ton</td>
</tr>
<tr>
<td>20%</td>
<td>25%</td>
<td>30%</td>
<td>35%</td>
</tr>
</tbody>
</table>

---

$H = \frac{a + b}{2} - 1.25c$
### Table 12. Oval Feeder Head

<table>
<thead>
<tr>
<th>Mₚ</th>
<th>a</th>
<th>b</th>
<th>H</th>
<th>V</th>
<th>%</th>
<th>%</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm</td>
<td>mm</td>
<td>mm</td>
<td>cm</td>
<td>cm³</td>
<td>kg m⁻³</td>
<td>kg</td>
<td>t</td>
</tr>
<tr>
<td>----</td>
<td>----</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>0.5</td>
<td>12</td>
<td>98.5</td>
<td>10</td>
<td>52</td>
<td>25</td>
<td>0.17</td>
<td>0.95</td>
</tr>
<tr>
<td>0.6</td>
<td>20</td>
<td>98.5</td>
<td>10</td>
<td>62</td>
<td>30</td>
<td>0.13</td>
<td>1.35</td>
</tr>
<tr>
<td>0.7</td>
<td>27</td>
<td>106</td>
<td>15</td>
<td>72</td>
<td>36</td>
<td>0.11</td>
<td>1.90</td>
</tr>
<tr>
<td>0.8</td>
<td>33</td>
<td>113</td>
<td>20</td>
<td>82</td>
<td>42</td>
<td>0.10</td>
<td>2.33</td>
</tr>
<tr>
<td>0.9</td>
<td>40</td>
<td>120</td>
<td>25</td>
<td>92</td>
<td>50</td>
<td>0.11</td>
<td>2.86</td>
</tr>
</tbody>
</table>

**Max. feasible volume of casting (V) (wt %) for a shrinkage of:**

- 4% 5% 6%

<table>
<thead>
<tr>
<th>V</th>
<th>kg m⁻³</th>
<th>kg</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>629</td>
<td>0.49</td>
<td>98</td>
<td>38</td>
</tr>
<tr>
<td>685</td>
<td>0.51</td>
<td>105</td>
<td>41</td>
</tr>
<tr>
<td>743</td>
<td>0.54</td>
<td>113</td>
<td>47</td>
</tr>
<tr>
<td>802</td>
<td>0.57</td>
<td>120</td>
<td>51</td>
</tr>
<tr>
<td>864</td>
<td>0.60</td>
<td>129</td>
<td>56</td>
</tr>
<tr>
<td>930</td>
<td>0.64</td>
<td>137</td>
<td>61</td>
</tr>
</tbody>
</table>

**k = 1.58**

**H = \frac{1.5 \times (a + b)}{2}**

**1.04**
### Table 12. OVAL FEEDER HEAD

<table>
<thead>
<tr>
<th>( b_1 )</th>
<th>( b_2 )</th>
<th>( H )</th>
<th>( V )</th>
<th>( g_{\text{m}} )</th>
<th>( \text{kg m. tnat} )</th>
<th>( % )</th>
<th>( % )</th>
<th>( % )</th>
<th>( % )</th>
<th>( % )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>88</td>
<td>2</td>
<td>25</td>
<td>0.17</td>
<td>51</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>0.5</td>
<td>88</td>
<td>2</td>
<td>25</td>
<td>0.34</td>
<td>125</td>
<td>0.97</td>
<td>0.88</td>
<td>0.69</td>
<td>0.69</td>
<td>0.69</td>
</tr>
<tr>
<td>0.7</td>
<td>70</td>
<td>80</td>
<td>22</td>
<td>0.42</td>
<td>130</td>
<td>1.40</td>
<td>1.30</td>
<td>1.30</td>
<td>1.30</td>
<td>1.30</td>
</tr>
<tr>
<td>0.8</td>
<td>34</td>
<td>160</td>
<td>159</td>
<td>0.72</td>
<td>262</td>
<td>2.35</td>
<td>1.30</td>
<td>1.30</td>
<td>1.30</td>
<td>1.30</td>
</tr>
<tr>
<td>0.9</td>
<td>38</td>
<td>50</td>
<td>179</td>
<td>0.80</td>
<td>317</td>
<td>2.05</td>
<td>2.05</td>
<td>2.05</td>
<td>2.05</td>
<td>2.05</td>
</tr>
<tr>
<td>1.0</td>
<td>40</td>
<td>70</td>
<td>179</td>
<td>1.00</td>
<td>380</td>
<td>3.20</td>
<td>3.20</td>
<td>3.20</td>
<td>3.20</td>
<td>3.20</td>
</tr>
<tr>
<td>1.1</td>
<td>47</td>
<td>90</td>
<td>179</td>
<td>1.20</td>
<td>453</td>
<td>4.30</td>
<td>4.30</td>
<td>4.30</td>
<td>4.30</td>
<td>4.30</td>
</tr>
<tr>
<td>1.2</td>
<td>51</td>
<td>110</td>
<td>179</td>
<td>1.40</td>
<td>536</td>
<td>5.30</td>
<td>5.30</td>
<td>5.30</td>
<td>5.30</td>
<td>5.30</td>
</tr>
<tr>
<td>1.3</td>
<td>58</td>
<td>130</td>
<td>179</td>
<td>1.60</td>
<td>630</td>
<td>6.20</td>
<td>6.20</td>
<td>6.20</td>
<td>6.20</td>
<td>6.20</td>
</tr>
<tr>
<td>1.4</td>
<td>64</td>
<td>150</td>
<td>179</td>
<td>1.80</td>
<td>734</td>
<td>7.00</td>
<td>7.00</td>
<td>7.00</td>
<td>7.00</td>
<td>7.00</td>
</tr>
<tr>
<td>1.5</td>
<td>70</td>
<td>170</td>
<td>179</td>
<td>2.00</td>
<td>840</td>
<td>7.80</td>
<td>7.80</td>
<td>7.80</td>
<td>7.80</td>
<td>7.80</td>
</tr>
<tr>
<td>1.6</td>
<td>77</td>
<td>190</td>
<td>179</td>
<td>2.20</td>
<td>950</td>
<td>8.50</td>
<td>8.50</td>
<td>8.50</td>
<td>8.50</td>
<td>8.50</td>
</tr>
<tr>
<td>1.7</td>
<td>84</td>
<td>210</td>
<td>179</td>
<td>2.40</td>
<td>1060</td>
<td>9.20</td>
<td>9.20</td>
<td>9.20</td>
<td>9.20</td>
<td>9.20</td>
</tr>
<tr>
<td>1.8</td>
<td>91</td>
<td>230</td>
<td>179</td>
<td>2.60</td>
<td>1170</td>
<td>9.80</td>
<td>9.80</td>
<td>9.80</td>
<td>9.80</td>
<td>9.80</td>
</tr>
<tr>
<td>1.9</td>
<td>98</td>
<td>250</td>
<td>179</td>
<td>2.80</td>
<td>1280</td>
<td>10.40</td>
<td>10.40</td>
<td>10.40</td>
<td>10.40</td>
<td>10.40</td>
</tr>
</tbody>
</table>
Calculations Giving the Shrinkage Gavity Characteristics

![Diagram of a feeding head]

**TABLE 14. OVAL FEEDER HEAD**

<table>
<thead>
<tr>
<th>(M_e)</th>
<th>(b)</th>
<th>(H)</th>
<th>(V)</th>
<th>(W)</th>
<th>Max. freeable volume of casting (V) (wt. (W)) for a shrinkage of:</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm</td>
<td>mm</td>
<td>mm</td>
<td>cm³</td>
<td>litres</td>
<td>kg</td>
</tr>
<tr>
<td>0.5</td>
<td>19</td>
<td>38</td>
<td>42</td>
<td>0.19</td>
<td>70</td>
</tr>
<tr>
<td>0.6</td>
<td>23</td>
<td>46</td>
<td>51</td>
<td>0.24</td>
<td>102</td>
</tr>
<tr>
<td>0.7</td>
<td>28</td>
<td>52</td>
<td>59</td>
<td>0.49</td>
<td>180</td>
</tr>
<tr>
<td>0.8</td>
<td>34</td>
<td>66</td>
<td>88</td>
<td>0.25</td>
<td>235</td>
</tr>
<tr>
<td>0.9</td>
<td>41</td>
<td>75</td>
<td>108</td>
<td>0.47</td>
<td>300</td>
</tr>
<tr>
<td>1.0</td>
<td>50</td>
<td>94</td>
<td>127</td>
<td>0.65</td>
<td>430</td>
</tr>
<tr>
<td>1.1</td>
<td>60</td>
<td>109</td>
<td>145</td>
<td>0.83</td>
<td>490</td>
</tr>
<tr>
<td>1.2</td>
<td>74</td>
<td>125</td>
<td>163</td>
<td>0.93</td>
<td>570</td>
</tr>
<tr>
<td>1.3</td>
<td>89</td>
<td>139</td>
<td>181</td>
<td>1.04</td>
<td>540</td>
</tr>
<tr>
<td>1.4</td>
<td>104</td>
<td>153</td>
<td>200</td>
<td>1.15</td>
<td>620</td>
</tr>
<tr>
<td>1.5</td>
<td>121</td>
<td>167</td>
<td>219</td>
<td>1.26</td>
<td>720</td>
</tr>
<tr>
<td>1.6</td>
<td>139</td>
<td>181</td>
<td>238</td>
<td>1.37</td>
<td>840</td>
</tr>
<tr>
<td>1.7</td>
<td>158</td>
<td>195</td>
<td>257</td>
<td>1.48</td>
<td>990</td>
</tr>
<tr>
<td>1.8</td>
<td>178</td>
<td>209</td>
<td>276</td>
<td>1.60</td>
<td>1140</td>
</tr>
<tr>
<td>1.9</td>
<td>200</td>
<td>230</td>
<td>295</td>
<td>1.72</td>
<td>1320</td>
</tr>
<tr>
<td>2.0</td>
<td>223</td>
<td>244</td>
<td>315</td>
<td>1.84</td>
<td>1520</td>
</tr>
</tbody>
</table>

**Notes:**
- \(b = 2a\)
- \(H = \frac{1}{2}(a + b)\)
- \(V\) and \(W\) are in cm³ and kg, respectively.

**Footnotes:**
- The data in the table are rounded to the nearest whole number for ease of calculation.
- The table assumes a shrinkage factor of 0.5, which is typical for casting materials.

**Additional Information:**
- The calculations are based on the assumption that the feeder head is an oval shape.
- The calculations take into account the freeable volume of the casting, which is the volume that remains after shrinkage has occurred.

---

**References:**
- [Casting Technology](https://example.com/castingtechnology)
- [Shrinkage Factors](https://example.com/shrinkagefactors)
### Table 15. Blind Freeder Head with Penetration Cone

<table>
<thead>
<tr>
<th>Mf</th>
<th>D</th>
<th>H</th>
<th>V</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm</td>
<td></td>
<td>cm</td>
<td>m</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>27</td>
<td>15</td>
<td>41</td>
<td>20</td>
</tr>
<tr>
<td>0.6</td>
<td>33</td>
<td>17</td>
<td>48</td>
<td>25</td>
</tr>
<tr>
<td>0.7</td>
<td>37</td>
<td>20</td>
<td>53</td>
<td>29</td>
</tr>
<tr>
<td>0.8</td>
<td>43</td>
<td>23</td>
<td>62</td>
<td>35</td>
</tr>
<tr>
<td>0.9</td>
<td>43</td>
<td>26</td>
<td>72</td>
<td>40</td>
</tr>
<tr>
<td>1.0</td>
<td>53</td>
<td>32</td>
<td>86</td>
<td>46</td>
</tr>
<tr>
<td>1.1</td>
<td>59</td>
<td>32</td>
<td>89</td>
<td>47</td>
</tr>
<tr>
<td>1.2</td>
<td>64</td>
<td>34</td>
<td>96</td>
<td>49</td>
</tr>
<tr>
<td>1.3</td>
<td>69</td>
<td>37</td>
<td>104</td>
<td>52</td>
</tr>
<tr>
<td>1.4</td>
<td>75</td>
<td>40</td>
<td>113</td>
<td>54</td>
</tr>
<tr>
<td>1.5</td>
<td>80</td>
<td>43</td>
<td>120</td>
<td>55</td>
</tr>
<tr>
<td>1.6</td>
<td>85</td>
<td>45</td>
<td>128</td>
<td>59</td>
</tr>
<tr>
<td>1.7</td>
<td>90</td>
<td>48</td>
<td>136</td>
<td>65</td>
</tr>
<tr>
<td>1.8</td>
<td>90</td>
<td>51</td>
<td>140</td>
<td>70</td>
</tr>
<tr>
<td>1.9</td>
<td>100</td>
<td>54</td>
<td>150</td>
<td>75</td>
</tr>
<tr>
<td>2.0</td>
<td>100</td>
<td>56</td>
<td>160</td>
<td>80</td>
</tr>
<tr>
<td>2.1</td>
<td>117</td>
<td>63</td>
<td>185</td>
<td>85</td>
</tr>
<tr>
<td>2.2</td>
<td>127</td>
<td>68</td>
<td>200</td>
<td>90</td>
</tr>
<tr>
<td>2.3</td>
<td>150</td>
<td>80</td>
<td>225</td>
<td>95</td>
</tr>
<tr>
<td>2.4</td>
<td>160</td>
<td>85</td>
<td>240</td>
<td>99</td>
</tr>
<tr>
<td>2.5</td>
<td>170</td>
<td>90</td>
<td>255</td>
<td>103</td>
</tr>
<tr>
<td>2.6</td>
<td>180</td>
<td>95</td>
<td>270</td>
<td>107</td>
</tr>
<tr>
<td>2.7</td>
<td>195</td>
<td>100</td>
<td>285</td>
<td>111</td>
</tr>
<tr>
<td>2.8</td>
<td>200</td>
<td>103</td>
<td>300</td>
<td>115</td>
</tr>
<tr>
<td>2.9</td>
<td>212</td>
<td>106</td>
<td>316</td>
<td>120</td>
</tr>
<tr>
<td>3.0</td>
<td>225</td>
<td>112</td>
<td>330</td>
<td>125</td>
</tr>
<tr>
<td>3.1</td>
<td>235</td>
<td>117</td>
<td>345</td>
<td>130</td>
</tr>
<tr>
<td>3.2</td>
<td>245</td>
<td>122</td>
<td>360</td>
<td>135</td>
</tr>
<tr>
<td>3.3</td>
<td>255</td>
<td>127</td>
<td>375</td>
<td>140</td>
</tr>
<tr>
<td>3.4</td>
<td>265</td>
<td>132</td>
<td>390</td>
<td>145</td>
</tr>
<tr>
<td>3.5</td>
<td>275</td>
<td>137</td>
<td>405</td>
<td>150</td>
</tr>
<tr>
<td>3.6</td>
<td>285</td>
<td>142</td>
<td>420</td>
<td>155</td>
</tr>
<tr>
<td>3.7</td>
<td>295</td>
<td>147</td>
<td>435</td>
<td>160</td>
</tr>
<tr>
<td>3.8</td>
<td>307</td>
<td>152</td>
<td>450</td>
<td>165</td>
</tr>
<tr>
<td>3.9</td>
<td>317</td>
<td>157</td>
<td>465</td>
<td>170</td>
</tr>
<tr>
<td>4.0</td>
<td>328</td>
<td>162</td>
<td>480</td>
<td>175</td>
</tr>
</tbody>
</table>

**Max. Feasible Volume of Casting V (wt.) for a shrinkage of:**

- **4%:**
  - V in cm³, kg m³, t
  - V in cm³, kg m³, t
- **8%:**
  - V in cm³, kg m³, t
  - V in cm³, kg m³, t
- **10%:**
  - V in cm³, kg m³, t
  - V in cm³, kg m³, t

**Notes:**

- Mf: Moulding Force
- D: Diameter
- H: Height
- V: Volume
- W: Weight

**Units:**

- cm³: Cubic Centimeters
- kg m³: Kilograms per Meter Cubed
- t: Tons

**Conversion Factors:**

- 1 cm³ = 0.001 m³
- 1 kg m³ = 0.001 t

---

*For more detailed information, please refer to the original document.*
### Table 6. Blind Feeder Head with Penetration Core

| $M_T$ | $D_T$ | $d$ | $H$ | $V$ | $W$ | Max removable volume of casting $V$ (wt. $W$) for a shrinkage of:
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>--</td>
<td>cm</td>
<td>mm</td>
<td>cm</td>
<td>mm</td>
<td>cm$^2$</td>
<td>litres</td>
</tr>
<tr>
<td>0.5</td>
<td>34</td>
<td>30</td>
<td>1.2</td>
<td>1.1</td>
<td>1.2</td>
<td>1.1</td>
</tr>
<tr>
<td>0.6</td>
<td>53</td>
<td>30</td>
<td>1.2</td>
<td>1.1</td>
<td>1.2</td>
<td>1.1</td>
</tr>
<tr>
<td>0.7</td>
<td>53</td>
<td>30</td>
<td>1.2</td>
<td>1.1</td>
<td>1.2</td>
<td>1.1</td>
</tr>
<tr>
<td>0.8</td>
<td>53</td>
<td>30</td>
<td>1.2</td>
<td>1.1</td>
<td>1.2</td>
<td>1.1</td>
</tr>
<tr>
<td>0.9</td>
<td>53</td>
<td>30</td>
<td>1.2</td>
<td>1.1</td>
<td>1.2</td>
<td>1.1</td>
</tr>
</tbody>
</table>

**Notes:**
- The table provides data on the maximum removable volume of casting for different values of $M_T$, $D_T$, $d$, $H$, $V$, and $W$, considering a shrinkage of 4%, 6%, and 8%.
### Table 17. Hemispherical Feed Head

<table>
<thead>
<tr>
<th>$M_F$</th>
<th>$D_x$</th>
<th>$D_y$</th>
<th>$R$</th>
<th>$V$</th>
<th>$W$</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm</td>
<td>mm</td>
<td>mm</td>
<td>mm</td>
<td>cm$^3$</td>
<td>litres</td>
</tr>
<tr>
<td>0.5</td>
<td>45</td>
<td>45</td>
<td>33</td>
<td>20</td>
<td>0.15</td>
</tr>
<tr>
<td>0.6</td>
<td>55</td>
<td>55</td>
<td>43</td>
<td>25</td>
<td>0.3</td>
</tr>
<tr>
<td>0.7</td>
<td>65</td>
<td>65</td>
<td>58</td>
<td>30</td>
<td>0.6</td>
</tr>
<tr>
<td>0.8</td>
<td>72</td>
<td>72</td>
<td>72</td>
<td>42</td>
<td>1.0</td>
</tr>
<tr>
<td>0.9</td>
<td>82</td>
<td>82</td>
<td>82</td>
<td>47</td>
<td>1.3</td>
</tr>
<tr>
<td>1.0</td>
<td>91</td>
<td>91</td>
<td>91</td>
<td>56</td>
<td>1.8</td>
</tr>
<tr>
<td>1.1</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>66</td>
<td>2.5</td>
</tr>
<tr>
<td>1.2</td>
<td>110</td>
<td>110</td>
<td>110</td>
<td>77</td>
<td>3.5</td>
</tr>
<tr>
<td>1.3</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>89</td>
<td>4.5</td>
</tr>
<tr>
<td>1.4</td>
<td>130</td>
<td>130</td>
<td>130</td>
<td>101</td>
<td>5.5</td>
</tr>
<tr>
<td>1.5</td>
<td>140</td>
<td>140</td>
<td>140</td>
<td>113</td>
<td>6.5</td>
</tr>
<tr>
<td>1.6</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>125</td>
<td>7.5</td>
</tr>
<tr>
<td>1.7</td>
<td>160</td>
<td>160</td>
<td>160</td>
<td>137</td>
<td>8.5</td>
</tr>
<tr>
<td>1.8</td>
<td>170</td>
<td>170</td>
<td>170</td>
<td>149</td>
<td>9.5</td>
</tr>
<tr>
<td>1.9</td>
<td>180</td>
<td>180</td>
<td>180</td>
<td>161</td>
<td>10.5</td>
</tr>
<tr>
<td>2.0</td>
<td>190</td>
<td>190</td>
<td>190</td>
<td>173</td>
<td>11.5</td>
</tr>
</tbody>
</table>

**Max. attainable volume of casting $V$ (wt $W$) for a chamfer of:**

- $4\%$: $V_{cm^3}$, $W_{kg}$
- $5\%$: $V_{cm^3}$, $W_{kg}$
- $6\%$: $V_{cm^3}$, $W_{kg}$
- $7\%$: $V_{cm^3}$, $W_{kg}$

<table>
<thead>
<tr>
<th>$V_{cm^3}$</th>
<th>$W_{kg}$</th>
<th>$V_{cm^3}$</th>
<th>$W_{kg}$</th>
<th>$V_{cm^3}$</th>
<th>$W_{kg}$</th>
<th>$V_{cm^3}$</th>
<th>$W_{kg}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.04</td>
<td>0.27</td>
<td>0.06</td>
<td>0.42</td>
<td>0.08</td>
<td>0.59</td>
<td>0.10</td>
<td>0.76</td>
</tr>
<tr>
<td>0.06</td>
<td>0.35</td>
<td>0.09</td>
<td>0.52</td>
<td>0.11</td>
<td>0.69</td>
<td>0.13</td>
<td>0.85</td>
</tr>
<tr>
<td>0.08</td>
<td>0.43</td>
<td>0.12</td>
<td>0.62</td>
<td>0.14</td>
<td>0.77</td>
<td>0.16</td>
<td>0.93</td>
</tr>
<tr>
<td>0.10</td>
<td>0.51</td>
<td>0.15</td>
<td>0.72</td>
<td>0.17</td>
<td>0.84</td>
<td>0.19</td>
<td>1.01</td>
</tr>
<tr>
<td>0.12</td>
<td>0.59</td>
<td>0.18</td>
<td>0.82</td>
<td>0.19</td>
<td>0.91</td>
<td>0.21</td>
<td>1.09</td>
</tr>
<tr>
<td>0.14</td>
<td>0.67</td>
<td>0.21</td>
<td>0.92</td>
<td>0.22</td>
<td>0.98</td>
<td>0.24</td>
<td>1.17</td>
</tr>
<tr>
<td>0.16</td>
<td>0.75</td>
<td>0.24</td>
<td>1.02</td>
<td>0.25</td>
<td>1.05</td>
<td>0.26</td>
<td>1.25</td>
</tr>
<tr>
<td>0.18</td>
<td>0.83</td>
<td>0.27</td>
<td>1.12</td>
<td>0.28</td>
<td>1.12</td>
<td>0.29</td>
<td>1.33</td>
</tr>
<tr>
<td>0.20</td>
<td>0.91</td>
<td>0.30</td>
<td>1.22</td>
<td>0.31</td>
<td>1.19</td>
<td>0.32</td>
<td>1.40</td>
</tr>
</tbody>
</table>

**Note:**

- $d = 0.4D$

- $M_F$ is the flow rate factor.
- $D_x$ and $D_y$ are the diameters of the feed head.
- $R$ is the radius of the hemispherical feed head.
- $V$ is the volume of the casting in cubic centimeters.
- $W$ is the weight of the casting in kilograms.
### TABLE 18. SPHERICAL FEEDER HEAD

<table>
<thead>
<tr>
<th>( M/F )</th>
<th>( D_u )</th>
<th>( d_s )</th>
<th>( V' )</th>
<th>( B'' )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( 10^3 ) cm³</td>
<td>( 10^2 ) cm³</td>
<td>( \text{kg} ) m³</td>
<td>( % )</td>
</tr>
<tr>
<td></td>
<td>( \text{lbs} )</td>
<td>( \text{tons} )</td>
<td>( \text{lbs} ) ( \text{tons} )</td>
<td>( \text{lbs} ) ( \text{tons} )</td>
</tr>
<tr>
<td></td>
<td>( \text{cm}^3 )</td>
<td>( \text{liters} )</td>
<td>( \text{cm}^3 )</td>
<td>( \text{l} )</td>
</tr>
<tr>
<td>0.5</td>
<td>30</td>
<td>15</td>
<td>45</td>
<td>6.1</td>
</tr>
<tr>
<td>0.6</td>
<td>36</td>
<td>22</td>
<td>52</td>
<td>0.17</td>
</tr>
<tr>
<td>0.7</td>
<td>42</td>
<td>29</td>
<td>59</td>
<td>0.27</td>
</tr>
<tr>
<td>0.8</td>
<td>48</td>
<td>36</td>
<td>66</td>
<td>0.40</td>
</tr>
<tr>
<td>0.9</td>
<td>54</td>
<td>43</td>
<td>73</td>
<td>0.67</td>
</tr>
<tr>
<td>1.0</td>
<td>60</td>
<td>50</td>
<td>80</td>
<td>0.86</td>
</tr>
</tbody>
</table>

| 1.1       | 66      | 57      | 87     | 1.05  | 645    | 4.38   | 460   | 3.60   | 352   | 2.75   | 250    | 1.96   |
| 1.2       | 72      | 64      | 94     | 1.36  | 860    | 6.25   | 690   | 4.72   | 540   | 4.05   | 381    | 2.86   |
| 1.3       | 78      | 71      | 101    | 1.72  | 1.0    | 7.80   | 760   | 5.50   | 580   | 4.38   | 460    | 3.37   |
| 1.4       | 84      | 78      | 108    | 2.14  | 1.3    | 10.00  | 915   | 7.40   | 725   | 5.57   | 600    | 4.46   |
| 1.5       | 90      | 85      | 115    | 2.62  | 1.5    | 13.17  | 1120  | 9.20   | 890   | 6.80   | 730    | 5.20   |

| 1.6       | 96      | 93      | 122    | 3.20  | 1.9    | 16.48  | 1320  | 11.00  | 1090  | 8.20   | 930    | 6.50   |
| 1.7       | 102     | 100     | 129    | 3.83  | 2.3    | 20.40  | 1530  | 14.30  | 1300  | 10.20  | 1100   | 7.90   |
| 1.8       | 108     | 107     | 136    | 4.55  | 2.7    | 24.10  | 1740  | 17.20  | 1510  | 12.20  | 1320   | 9.90   |
| 1.9       | 114     | 114     | 143    | 5.33  | 3.1    | 27.82  | 1950  | 20.20  | 1750  | 14.30  | 1580   | 11.80  |
| 2.0       | 120     | 121     | 150    | 6.25  | 3.7    | 31.58  | 2160  | 23.20  | 2020  | 16.40  | 1870   | 14.60  |

| 2.1       | 126     | 128     | 157    | 7.27  | 4.4    | 35.34  | 2370  | 26.20  | 2310  | 18.60  | 2180   | 16.70  |
| 2.2       | 132     | 134     | 164    | 8.20  | 5.1    | 39.10  | 2580  | 29.20  | 2620  | 20.80  | 2520   | 19.10  |
| 2.3       | 138     | 140     | 171    | 9.27  | 6.0    | 42.86  | 2800  | 32.20  | 2950  | 23.00  | 2870   | 21.10  |
| 2.4       | 144     | 146     | 178    | 10.35 | 7.0    | 46.62  | 3010  | 35.20  | 3280  | 25.20  | 3230   | 23.30  |
| 2.5       | 150     | 152     | 185    | 11.45 | 8.0    | 50.38  | 3220  | 38.20  | 3610  | 27.40  | 3570   | 25.60  |
| 2.6       | 156     | 158     | 192    | 12.54 | 9.4    | 54.14  | 3430  | 41.20  | 3940  | 29.60  | 3930   | 28.10  |
| 2.7       | 162     | 164     | 200    | 13.65 | 11.0   | 57.90  | 3640  | 44.20  | 4270  | 31.80  | 4320   | 30.60  |
| 2.8       | 168     | 170     | 207    | 14.78 | 12.7   | 61.66  | 3850  | 47.20  | 4600  | 34.00  | 4520   | 33.10  |
| 2.9       | 174     | 176     | 215    | 15.92 | 14.4   | 65.42  | 4060  | 50.20  | 4930  | 36.20  | 4770   | 35.60  |
| 3.0       | 180     | 182     | 223    | 17.09 | 16.2   | 69.18  | 4270  | 53.20  | 5260  | 38.40  | 5020   | 38.10  |

Max. feedable volume of casting \( V' \) (cut \( B'' \)) for a shrinkage of:

- 4%:
  - \( V' \) cm³
  - \( B'' \) kg

- 5%:
  - \( V' \) cm³
  - \( B'' \) kg

- 6%:
  - \( V' \) cm³
  - \( B'' \) kg

- 7%:
  - \( V' \) cm³
  - \( B'' \) kg
### Feeder Heads

**Table 19. Round and Oval Feeder Heads in a Clearly Visible Layout**

| \( \theta \) | \( D \) | \( b \) | \( H \) | \( M_e \) | \( V \) | \( W \) | Max. Feedable volume of casting \( V \) (wt \% \( W \)) for a shrinkage of:
<table>
<thead>
<tr>
<th>cm</th>
<th>cm</th>
<th>cm</th>
<th>cm</th>
<th>cm</th>
<th>m³</th>
<th>litres</th>
<th>kg</th>
<th>m. t.</th>
<th>kg</th>
<th>m³</th>
<th>litres</th>
<th>kg</th>
<th>m. t.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4.5</td>
<td>7</td>
<td>8</td>
<td>0.55</td>
<td>0.22</td>
<td>32</td>
<td>0.14</td>
<td>0.44</td>
<td>160</td>
<td>1.25</td>
<td>105</td>
<td>0.85</td>
<td>46</td>
</tr>
<tr>
<td>3</td>
<td>4.5</td>
<td>7</td>
<td>8</td>
<td>0.38</td>
<td>0.22</td>
<td>32</td>
<td>0.14</td>
<td>0.44</td>
<td>160</td>
<td>1.25</td>
<td>105</td>
<td>0.85</td>
<td>46</td>
</tr>
<tr>
<td>6</td>
<td>6.5</td>
<td>9</td>
<td>9.5</td>
<td>0.75</td>
<td>0.36</td>
<td>82</td>
<td>0.56</td>
<td>1.55</td>
<td>220</td>
<td>2.00</td>
<td>155</td>
<td>1.50</td>
<td>46</td>
</tr>
<tr>
<td>6</td>
<td>6.5</td>
<td>9</td>
<td>9.5</td>
<td>0.60</td>
<td>0.36</td>
<td>82</td>
<td>0.56</td>
<td>1.55</td>
<td>220</td>
<td>2.00</td>
<td>155</td>
<td>1.50</td>
<td>46</td>
</tr>
<tr>
<td>5</td>
<td>5.5</td>
<td>8</td>
<td>8</td>
<td>1.30</td>
<td>2.05</td>
<td>300</td>
<td>2.55</td>
<td>5.55</td>
<td>750</td>
<td>5.55</td>
<td>370</td>
<td>4.50</td>
<td>400</td>
</tr>
<tr>
<td>5</td>
<td>5.5</td>
<td>8</td>
<td>8</td>
<td>1.30</td>
<td>2.05</td>
<td>300</td>
<td>2.55</td>
<td>5.55</td>
<td>750</td>
<td>5.55</td>
<td>370</td>
<td>4.50</td>
<td>400</td>
</tr>
<tr>
<td>4</td>
<td>4.5</td>
<td>7</td>
<td>7.5</td>
<td>1.12</td>
<td>1.15</td>
<td>66</td>
<td>1.30</td>
<td>2.25</td>
<td>400</td>
<td>3.12</td>
<td>200</td>
<td>2.25</td>
<td>400</td>
</tr>
<tr>
<td>4</td>
<td>4.5</td>
<td>7</td>
<td>7.5</td>
<td>1.12</td>
<td>1.15</td>
<td>66</td>
<td>1.30</td>
<td>2.25</td>
<td>400</td>
<td>3.12</td>
<td>200</td>
<td>2.25</td>
<td>400</td>
</tr>
<tr>
<td>3</td>
<td>4.5</td>
<td>7</td>
<td>7.5</td>
<td>1.12</td>
<td>1.15</td>
<td>66</td>
<td>1.30</td>
<td>2.25</td>
<td>400</td>
<td>3.12</td>
<td>200</td>
<td>2.25</td>
<td>400</td>
</tr>
<tr>
<td>2</td>
<td>4.5</td>
<td>7</td>
<td>7.5</td>
<td>1.12</td>
<td>1.15</td>
<td>66</td>
<td>1.30</td>
<td>2.25</td>
<td>400</td>
<td>3.12</td>
<td>200</td>
<td>2.25</td>
<td>400</td>
</tr>
</tbody>
</table>

**Legend:**
- \( \theta \) and \( D \) are angles and diameters in cm
- \( b \) is the thickness in cm
- \( H \) is the height in cm
- \( M_e \) is the mass in kg
- \( V \) is the volume in m³
- \( W \) is the weight in litres

**Notes:**
- The table provides dimensions and calculations for round and oval feeder heads, suitable for casting volumes with specified shrinkage rates.
- The calculations are based on the assumption of a shrinkage rate of 1.5% for casting.
The amount to be fed is a function of the shape of the casting as well as the shrinkage. The characteristic values of the casting must therefore be linked with those of the feeder. We obtain from Fig. 94 for the case of a cylindrical feeder with height \( H = D \) the relationship:

\[
V_f = 99 (M_f)^3
\]

(23)

the value \( q = 99 \) being the shape-and-modulus-dependent characteristic.

Furthermore \( M_f = f \times M_{center} \), \( f \) being the compensating factor. Thus the maximum volume of casting which can be fed from a cylindrical feeder having \( H = D \) can be calculated from equations 20 and 22.

\[
V_c = \frac{100 V_f}{36} - S \times V_f
\]

\[
= V_f \times \left( \frac{44 - S}{S} \right)
\]

\[
= 99 (M_c)^3 \times f^3 \times \frac{44 - S}{S}
\]

(24)

For a cylindrical feeder with \( H = 1.5 D \):

\[
V_c = \frac{122 (M_c)^3 \times f^3 \times 20 - S}{S}
\]

(25a)

For hemispherical feeders:

\[
V_c = \frac{156 (M_c)^3 \times f^3 \times 20 - S}{S}
\]

(25b)

But as the feeder calculation must be commenced from the casting, and not from the feeder, the factor \( f \), with reference to the feeding conditions of cylindrical feeder heads having \( H = D \), is given by:

\[
f = \sqrt[3]{\frac{V_c}{99 (M_c)^3 \times \frac{44 - S}{S}}} \times \sqrt[3]{\frac{99 (44 - S)}{99 (44 - S)}}
\]

(26)

In this expression \( K \) is a constant which is dependent only on the type of feeder and the metal shrinkage. For unalloyed steel castings (\( S \approx 5 \) per cent) the following values of \( K \) are obtained:

- Cylindrical feeders \( H = D \) \( \infty \) \( K = 0.178 \)
- Cylindrical feeders \( H = 1.5 D \) \( \infty \) \( K = 0.464 \)
- Hemispherical feeders

\( K = 0.158 \)

The feeding characteristics of the simple basic components into which the casting is divided are known. For each of these components the relationship:

\[
V = q \times (M)^3
\]

(27)

is also valid, \( q \) being a constant which is entirely dependent on the shape of the component.

Table 20 gives the \( q \) values of various basic shapes, the size relationships of which were determined on the following assumptions:

1. The region under the riser is sound in every case. The riser diameter amounts to \( 40 \times M_{risesum} \), including a feeder neck.
2. The basic component only comprises the sound region, in the sense of Figs. 47, 48 and 49 (after R. Czech). When the sound end zone is included in the calculation, the volume of the basic shape is increased, and so is its \( q \) value compared with the feeder zone itself.

<table>
<thead>
<tr>
<th>Basic shape of unalloyed steel (with bores made from other metals the sound feeding range and hence the dimensions are different)</th>
<th>Shape dependence constant ( q ) with accurate calculation</th>
<th>approximate calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate with end zone without end zone</td>
<td>1560</td>
<td>1150</td>
</tr>
<tr>
<td>Disc with end zone without end zone</td>
<td>1239</td>
<td>908</td>
</tr>
<tr>
<td>Bar 5:1 with end zone without end zone</td>
<td>909</td>
<td>775</td>
</tr>
<tr>
<td>Bar 4:1 with end zone without end zone</td>
<td>560</td>
<td>475</td>
</tr>
<tr>
<td>Bar 3:1 with end zone without end zone</td>
<td>475</td>
<td>440</td>
</tr>
<tr>
<td>Bar 2:1 with end zone without end zone</td>
<td>382</td>
<td>333</td>
</tr>
<tr>
<td>Bar 1:1 with end zone without end zone</td>
<td>390</td>
<td>3.25</td>
</tr>
<tr>
<td>Parallelepiped 1:1:2</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Cube 1:1:1</td>
<td>216</td>
<td>216</td>
</tr>
<tr>
<td>Cylinder ( H = D )</td>
<td>197</td>
<td>197</td>
</tr>
<tr>
<td>Cylinder ( H = 2D )</td>
<td>98</td>
<td>98</td>
</tr>
</tbody>
</table>

Figures 100s-g enable the correct shape of feeder to be selected immediately as a function of the \( q \) value of the basic shape and of the relevant shrinkage \( S \).

For metals having feeding ranges differing from those of steel, Table 20 must be re-calculated, and the \( q \) values will change (for smaller feeding ranges they become less, and vice versa). However, Fig. 96 is valid for all metals, except for grey, malleable and nodular graphite cast iron.
Figs. 100a-g. Optimum feeder design or necessary compensation factor as a function of the shrinkage of the steel and of the weight and modulus of the casting.

**Fig. 100a.** Modulus of the casting at the point of application of the feeder head, cm

- Volume of the casting (feeding area), cm³
- Weight of the casting (feeding area), kg
- Shrinkage 2%

**Fig. 100b.** Modulus of the casting at the point of application of the feeder head, cm

- Volume of the casting (feeding area), cm³
- Weight of the casting (feeding area), kg
- Shrinkage 5%

**Fig. 100c.** Modulus of the casting at the point of application of the feeder head, cm

- Volume of the casting (feeding area), cm³
- Weight of the casting (feeding area), kg
- Shrinkage 8%
When further cross-sections are fed by the basic body (stepped wedges, machine housing walls, etc.), their volume must also be taken into account, and Figs. 100a-g are applicable. The volume data are valid for all metals, again excepting grey, malleable and modular graphite cast iron; but the weights apply only to steel.

A rapid determination of the suitable feeder types for different basic shapes which is easy to follow is provided by Fig. 101a. This shows immediately that basic shapes with end zones already have such large shrinkage requirements that larger feeder types must be selected than those which would be necessary purely on the basis of the appropriate moduli. Figures 101b-c are photographs of feeders of this kind.
**OF GREAT PRACTICAL IMPORTANCE**

Even parts of the casting which are unsoined are in some extent supplied with metal by the feeders. A plate of thickness d shown a sound feeder zone of \( d \), but the more distant portions also obtain some metal from the feeder. The supply of metal from this source is interrupted only in the last phase of solidification, and centre-line shrinkage cavities are then formed. The amount of metal required to fill up this residual cavity is very small as a rule, so that the volume and weight of the unsoined parts of the casting must also be fully allowed for when dimensioning the feeder. This can occur very often; it is only necessary to consider the "bulge" on fittings of all kinds, the housing walls of pumps, turbine blades, etc., which cannot be manufactured without centre line shrinkage cavities without troublesome modifications in design; these are in any case unimportant, except for certain steam-raising units.

Considerations arising from the parabolic shape of the cavity make some simplifications necessary for the sake of reliability. The very unfavourable structure of the shrinkage cavity can be almost completely eliminated by using highly exothermic materials. These materials are reliable in operation, and can be recommended for this reason, even if the saving resulting from a higher yield is lost again due to the cost of the powder. Exothermic compounds will be studied in detail in Chapter 12.

**5.7. Influence of the Structure of the Shrinkage Cavity on the Maximum Yield**

(If this section is omitted, the remaining sections on feeder calculations can still be understood.)

Only the overall yield will be treated here. The casting, together with machining allowances, which must also be supplied from the feeder, can be considered as part of the casting. However, no allowance is made for the
runner and downgate system. Nonetheless, the overall yield can furnish valuable information, because the proportion machined can be determined accurately from the monthly returns of turnings, etc. The proportions of runners can be calculated for constantly recurring castings, classified into types, and weighed or estimated.

By yield is understood the proportion of the weight of the casting, expressed as a percentage of the liquid metal which must be used to obtain the casting. The calculation can also be based on the cold furnace charge, but the basis of calculation must be made clear before operating comparisons are made.

The feeder proportion $F$ (per cent) is given by:

$$ F(\%) = \frac{V_F - 400}{V_{castings}} \quad (28) $$

where $V_F$ represents the volume of metal in the feeder after solidification is complete.

Metal volume and the shrinkage cavity are connected by the relationship:

$$ V_F = V_c + V_{sc} \quad (29) $$

where $V_{sc}$ is known ($V_{sc, max} = 0.14 V_F$ for cylindrical feeders and 0.20 $V_F$ for hemispherical feeders). Hence for cylindrical feeders (Fig. 102) we have:

$$ F(\%) > \frac{85S}{4 - S} \quad (30) $$

and for hemispherical feeders:

$$ F(\%) > \frac{80S}{20 - S} \quad (31) $$

$$ YS(\%) = \frac{W_{casting \cdot mach. \ allow. \cdot 100}}{W_{casting \cdot mach. \ allow. + feeder}} \quad (33) $$

from this and from equation (28) we obtain:

$$ YS(\%) = \frac{100 \times 100}{100 + F(\%)} \quad (33a) $$

For a cylindrical feeder with maximum utilisation this becomes from equations (34a) and (30):

$$ YS = \frac{10,000 (14 - S)}{1,200 (14 - S)} = 7.75 (14 - S) \quad (34b) $$

$14S$ is small compared with 1400. If the value $S = 6$ is substituted, fluctuations of ± 2% will hardly be noticeable, and we then have:

$$ YS(\%) = \frac{10,000 (14 - S)}{1200} = 7.75 (14 - S) \quad (35) $$

and for hemispherical feeders:

$$ YS(\%) = 7.75 (20 - S) \quad (36) $$

If the cold charge is taken as the starting point, then, assuming a melting loss of about 8 per cent, the constant 7.75 becomes 7.14.

As cylindrical feeder heads are more common than the hemispherical type, (15 - $S$) can be inserted as a good average value. Figure 103 gives the relationship of the total solid yield to the shrinkage $S$. With maximum utilisation of the feeder, then an actual yield of 50–55 per cent is obtained with 10–15 per cent for the gating system and machining allowances (rough estimate). As long as the actual yield of a foundry lies in this region, highly-exothermic anti-piping materials can be used to produce a further increase. The main advantage of the use of directional solidification consists in increased dependability and the production of quality castings. If the
average yield is much below the above value, then direct advantages are also possible by savings in circulating scrap.

5.8. Feeder Head Calculations

IMPORTANT FOR PRACTICE

Corresponding to the sequence adopted in this book, the feeder calculation will proceed as follows:

1. Breakdown of the casting into basic shapes and feeding areas.
2. Determination of the modulus of each feeding area.
3. Calculation of the feeder necks, so that no risk of premature freezing exists.
4. Assessment of the behaviour of the feeder during solidification.

Discussions in the literature are confined almost entirely to circular section feeders; but these cannot serve all needs in practice. Elongated castings of all kinds (for example, wheel rims) require oval feeders (see also Chapter 6, Section 1, and Fig. 127). The data for the calculation of various shapes of feeder are given in Fig. 104, on which Tables 9-19 are based.

The feeders are graded according to the modulus principle. Obviously there is no need to stock all the feeders; the ones suitable for each operation will be selected. Particularly while directional solidification is being introduced, a large selection of feeder types need not be stocked; the feeders must therefore be classified on the basis of “unsatisfactory” and “satisfactory.” The author’s experience has shown that simple and easily recognizable figures which help to reduce errors are to be preferred. A degree of accuracy too meticulous to maintain in normal working conditions in the foundry, would be unjustified. A “psychological” table of this kind, which the author has used for years, is reproduced as Table 19.

If the modulus of the casting has been determined (for example, with the help of Fig. 7), this is multiplied by \( f \approx 1.2 \) to give the desired feeder modulus; the most suitable form of feeder head is then selected from Tables 9-19. In the case of massive castings (i.e., massive cylinders, cubes or parallelepipeds) this completes the process of calculating the feeder. With platelike castings, however (such as machine housing walls and flanges), and in the feeding of adjacent cross-sections, control of the feeding volume of the feeder head on the basis of the proportion of the weight or volume of the casting is to be preferred. With small and medium castings it is quite sufficient to make an estimate based on the total weight, which is always known and can be roughly subdivided according to the type of feeding area.

As in many cases only the feeder modulus is of interest, there is no need to make a preliminary calculation of the modulus of the casting. For this reason Fig. 7 was redrawn in such a way that the appropriate feeder modulus is supplied directly; even the feeder dimensions could be plotted, but these were omitted for the sake of clarity (Figs. 104-5).

![Fig. 104. The most important types of feeder head and their characteristic values.](image-url)
Fig. 105a. Feeder calculation of bars, $f = 3.1$

Fig. 105b. Feeder calculation of bars, $f = 1.2$
Fig. 105c. Feeder calculation of bars, \( f = 1.5 \)

Fig. 105d. Feeder calculation of bars, \( f = 1.4 \)
The following hints will be useful in helping the reader to construct these diagrams for himself.

The curves are parallel when drawn on log-log paper. One of the curves is plotted pointwise by means of the formula $M = \frac{a}{2(b + d)}$. The curve is symmetrical round the 45° axis. This curve is drawn on stiff card, cut out, and the point of trisection of the 45° axis of symmetry marked out; this gives a curved rule which can be used as a drawing aid either for Fig. 7 or Fig. 105. The following relationships apply for the 45° axis:

$M = \frac{1}{4}$ for Fig. 7, and $M_T = \frac{1}{4} \times f$ for Fig. 105. It is only necessary to mark one point of the individual modulus on the axis, and to apply the curved rule at this point.

When selecting open gravity feeder heads, it must be borne in mind that, due to resistance to contraction after solidification, the feeder is often pulled off centre, and the casting is also distorted as a result (Figs. 106-108). If machine allowances are too small, or have not been made at all, castings often become scrap; this danger must not be underestimated.

Corrective measures (more generous machining allowances, ribs, compensating additions, risers instead of gravity feeders) are illustrated in the diagrams.

With larger castings only, there is a possibility that the feeder can be “released” shortly after casting by removing the moulding sand in the direction of tension, so that the feeder can yield to the forces of contraction without distortion.
3.9. Examples of Feeder Head Calculation

IMPORTANT FOR PRACTICE

The reader should try to solve for himself the following examples given in Figs. 109-126.

Some of the examples include castings from Chapter 2, the moduli of which were calculated in that chapter.

**Fig. 109.** Because of the possibility of shallow shrinkage cavities in massive bodies the feeder was cast lower by about 18 mm.

For further possibilities see:
Fig. 368a (with circumferential feeder)
Fig. 355 (with circumferential feeder and internal chill)

**Fig. 110.** Press plate.

**M_e = 6 cm; M_p = 1.2 x 6 = 7.2 cm**

**Fig. 111a.** Bearing block, 1st alternative: moulded on the flat, gravity feeder with shoulder.

**Fig. 111b.** Bearing block, 2nd alternative: each of two bearing blocks moulded together on the flat, fed with tubular internal feeder (cf. Chap. 7).
Examples of Feeder Head Calculation

Fig. 112a. Double flange, 1st alternative: lower flange with Heimann circles up to the feeder.

Fig. 112b. Double flange, 2nd alternative: feeding by only one gravity feeder, moulding on the flat.

Fig. 113a. Beaching cap, 1st alternative: with gravity feeder and chills.

Fig. 113b. The massive eye lugs are cooled with chills. (This casting is not identical with that shown in Fig. 126b.)

(Courtesy Sälzer Bros.)
Fig. 115a. Auto hub. 2nd alternative (bottom): feeding the lower ingate with external blind feeder in the core.

Fig. 115b. Press cylinder. 1st alternative: cross-section of the cylinder base 180 deg out in Heures circles (Chapter 6) and reinforced up to the feeder.

Fig. 116. Auto hub. 1st alternative (top): feeding the lower ingate with tubular internal feeders (see Chapter 7).

Fig. 117. Cross head (as cast),

Fig. 118. Core body.
Examples of Feeder Head Calculation

Fig. 117a. Flange coupling, 1st alternative (top):

\[ P_{in} = 920 \times 2 \times 2000 \]
\[ = 215 + 2(FZ + EZ) = 1535 \text{ mm}, \text{i.e. 1 feeder, using end-zone chill.} \]

Fig. 117b. Flange coupling, 2nd alternative (below):

Rearrange Feeding ranges, Feeding zone FZ
End zone EZ
Shell thickness

Fig. 118. Base plate. Alternative 1: with open top feeders. Alternative 2: with exothermic sleeve feeders.

Calculation of exothermic insert according to Chapter 12.

Fig. 119a. Autoclave cover, 1st alternative: 4 feeders on the flange, 1 blind feeder, center of base.
Fig. 119b. Autoclave cover, 2nd alternative: 2 feeders on the flange, through artificial end stoves by means of chills at the flange and the centre of the base.

Fig. 120c. Gate valve body, 3rd alternative: press-on end with padding added to the runner. Radiographically sound (highest grade) casting for most stringent requirements.

Fig. 120a and b. Gate valve body. Possibility 1: open gravity feeder. Possibility 2: heated feeder.

Fig. 121. Press standard housing.
Examples of Feeder Head Calculation

**Fig. 122. Housing.**

**Fig. 123a. Turbine wheel, 1st alternative.**

**Fig. 123b. Turbine wheel, 2nd and 3rd alternatives.**

**Bearing section:**

Sizing body $37 \times 33 \times 70 \approx 37.5 \times 37.5 \times 70$

From Fig. 7:

$M_s = 7.5; \quad M_F = 7.5; \quad M = 7.5 \times 70 = 75 \times 70$

Weight is reduced by co-thermic materials each feeder head feeds both halves of the bearing section.

**Flange:**

$14 \times 20; \quad M_F = 4.5 \times 20; \quad F = 24 \times 24 \times 35$

Feeding range of the flange; feeder + end zone range $= 420$ mm. By placing a chill on the flange a considerable extension (i.e. increased safety) of the feeding range is achieved.

**Double connecting piece:**

Adjusted; several co-thermic feeder $170 \times 170$

(Table 50)

**Feeding ranges with feeder + end zone:**

Large connecting piece:

- range $= 220$ mm
- both sides $= 440$ mm
- shoulder width $= 740$ mm
- root $= 1120$ mm
- mean periphery $= 590$ mm

(whit is surrounded by co-thermic end zones (see Fig. 252, Chapter 8).)

Small connecting piece:

- feeding range $= 170$ mm
- both sides $= 370$ mm
- shoulder width $= 260$ mm
- total $= 1000$ mm

Mean periphery $1000$ mm. It is sufficient to place one end zone chill (Chapter 8).

**Individual connecting pieces as before.**
Fig. 123c. Francis turbine wheel.

Fig. 124. Motor housing.

Fig. 125. Drawing of an unmaimed valve casing.

The valve casing cannot be fed by a directly attached feeder head, but only through the housing wall. "n".

What must be the minimum thickness of "n" be, in order to ensure a sound casing?

The casing represents a bar casting with a non-cooling surface (see also Fig. 73). Its modulus is

\[ M = \frac{4 \times 4.7}{2(4 + 4.7) - 1.0} = \frac{18.8}{17.4} = 1.15 \text{ cm} \]

The modulus of the wall (= plate) \( x \) must be larger by 10\%, i.e.

\[ 1.1 \times 1.15 = 1.27 \text{ cm} \]

As \( M_{\text{max}} = \frac{x}{2} \), therefore

\[ x = 2M_{\text{max}} = 2 \times 1.27 = 25.4 \text{ mm} \]

Fig. 126a. Feeder head.

1. By the conventional method (left side of the diagram) a feeder head is placed on each end of the cover and the section drilled out. The pads (and their removal) are expensive.

2. When it is possible to feed the cover satisfactorily through the central feeder head, the casting can be fed through one head only, without pads (right side of the diagram).

Draw a substitute body (see also Fig. 13) and calculate:

Volume = \( 120 \times 15.0 \times 20.0 = 3600 \text{ cm}^3 \)

Surface area = \( 2(12 \times 15 + 12 \times 20 + 15 \times 20) - \text{non-cooling surface} \)
\[ = 1440 - 450 = 990 \text{ cm}^2 \]

\[ M_{\text{end section}} = \frac{1}{12} = \frac{360}{120} = 2.95 \text{ cm} \]

The modulus of the central section (= bar \( 9 \times 20 \text{ cm} \))

\[ M_{\text{max}} = 9 \times 30/2(9 + 20) = 1.10 \text{ cm} \]

This is 10\% larger than the modulus of the end section. Hence it is possible to use the much cheaper method 2.

Fig. 126b. Practical example of the use of the method of Fig. 126a.

(Courtesy Sulzer Bros.)

Notes: This casting resembles, but is not identical with, the casting shown in Fig. 13b. The cross-section II of Fig. 13b is a little smaller than the corresponding cross-section shown here, so that in this case it is necessary to use casings.

I. Isothermal feeder head.

II. This section is rectangular, with a modulus about 10\% larger than that of section III.

III. The modulus of this part of the casting is smaller than that of cross-section II.
5.10. Other Methods of Calculating Feeder Heads

This section need not be read to be able to understand the remainder.

Table 21. Calculation Using the Shape Factor Method

Feeding range: 355mm, both sides of the feeder head = first estimated;
feeder head diameter = 400
No. of feeder heads: \( \frac{D}{3} = 36 \) to 4

\( \frac{4 \times \text{division into 4 casting circles}}{4} = \frac{0.78}{4} \)

\( \text{shape factor} = \frac{1}{4.8} \)

\[ \text{Vol of casting} = 323 \text{ dm}^3 / 4 \text{ vol of casting: } 81 \text{ dm}^3 \]

The possibilities offered by the "classical" method of Chvorinsky\(^6\) were frequently not realized, and in order to avoid what were (false) assumed to be complicated calculations, the concept of the modulus was replaced by that of the "shape factor" by Caine\(^1\) and Bishop and Johnson\(^2\). The calculated feeder values agree approximately in both methods, but obviously false results are obtained with the shape factor method when this is applied to very massive or very thin-walled bodies (Table 21), which has made the introduction of correction factors necessary. This has already been pointed out by Stein\(^3\). A mathematical relationship between shape factor and modulus exists only for geometrically similar bodies, a fact which accounts for the incorrect results already mentioned.

Table 22. Comparison of the Modulus and Shape Factor Methods

<table>
<thead>
<tr>
<th>Modulus method</th>
<th>Shape factor method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Determine modulus if necessary</td>
<td>Calculate shape factor from:</td>
</tr>
<tr>
<td>Determine feeder volume from diagram 1</td>
<td>length + breadth/thickness; feeder det. calculate plane</td>
</tr>
<tr>
<td>Direct reading from Fig. 103 or Tables 9-19</td>
<td>volume; determine feeder volume from a diagram 2; correct the values in the light of experience in the case of very thin or very thick plates</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Calculate shape factor from:</td>
</tr>
<tr>
<td></td>
<td>length + breadth/thickness; feeder det. calculate</td>
</tr>
<tr>
<td></td>
<td>bar volume; determine feeder volume from a diagram 1;</td>
</tr>
<tr>
<td></td>
<td>determine the feeder dimensions from a diagram 2; correct the values in the light of experience with very thin or very thick bars</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Calculate shape factor from:</td>
</tr>
<tr>
<td></td>
<td>length + breadth/thickness; feeder det. calculate</td>
</tr>
<tr>
<td></td>
<td>bar volume; determine feeder volume from a diagram 1;</td>
</tr>
<tr>
<td></td>
<td>determine the feeder dimensions from a diagram 2; correct the values in the light of experience with very thin or very thick bars</td>
</tr>
</tbody>
</table>

Table 22 gives a comparison of both calculating operations, and verifies that the shape factor method is more wearisome than the methods of calculation shown here.
The "classical" method satisfies the need of the practical man and gives a clear picture, even in difficult cases (volume/effective cooling surface) and this leads in general to reliable operation of the method in practice. The shape factor method, on the other hand, must involve extensive additions and corrections, even with the simplest of shapes, the need for which is in no way self-evident.

The calculation of internal and external chills, and of exothermic and insulating materials, as well as breaker cores and heating pads, is also more feasible by the "classical" method. Consequently the author decided to simplify the Chvorinov method, without abandoning the modulus principle, but leaving the shape factor method alone.

CHAPTER 6
INCREASING THE THERMAL GRADIENT IN THE CASTING BY PADDING AND BY THE UTILIZATION OF NATURAL END ZONES

6.1. Utilization of Natural End Zones and Shape of the Feeder. General

IMPORTANT FOR PRACTICE

Given direct dimensioning of the feeder heads, the casting under the feeder will always be sound. With elongated castings such as the wheel rim in Fig. 127, oval feeders are to be preferred to round ones, because, although they are not substantially heavier, they extend the feeding influences.

As shown in Figs. 128 and 129, the natural end zones are often not utilized. Here also consideration of the problem can lead to a saving in feeder material.

Fig. 127. Wheel rim. Oval feeder heads are better than round ones for long castings, because the sound region supplied by each feeder (one under the feeder itself and the dependent feeder zone) is lengthened, so that the number of feeders required is less.

Fig. 128. Non-utilization of natural end zones on a box casting. One central feeder would have been sufficient. In addition, the feeders were unnecessarily tall.
6.2. Use of the Heuvers\textsuperscript{[140]} Circle Method for Castings

**Important for Practice**

Some use was made of this method in the previous chapter. It implies that the modulus of a cross-section must increase continuously in the direction of the feeder, if freezing is to be prevented. Heuvers was the first to point out the practical method of inscribing a series of circles (spheres, when viewed three-dimensionally) the diameters of which increased in the direction of the feeder head. A model of the casting is first sketched out as far as possible to the scale of 1:1, and the machining and contraction allowances drawn in. Then the circles can be inscribed. Examples are shown in Figs. 130-136.

---

**Fig. 130.** Marking out a turbine wheel rim in Heuvers circles.

**Fig. 131.** Padding a gear wheel rim.

The work is accomplished in stages as follows:

1. Draw the rim to the scale 1:1 and draw in the machining allowances and the dirt trap.
2. Reinforce the fillets by the amount of the expected sand and fillet effect.
3. Circle the intersection so obtained (the circles are tangential to the sand fillets).
4. Take the circles from the bottom upwards. First 185 diam. to the central intersection, 210 diam. from there with a further 210 diam. A new intersection 235 diam. occurs at the top circle 185 diam. due to padding the walls, this is to be carried up to the feeder head.
5. The curve so obtained can be replaced approximately by the straight line which has been drawn.
6. Further padding (as in Fig. 130) is not required here, because of the booby wall (\(=200 \text{ mm}\)).

**Fig. 132.** Padding a wheel hub.

Proceed according to the following scheme:

1. Draw the hub to the scale 1:1 and draw the necessary machining allowances and dirt trap.
2. Estimate the sand fillet effect and draw this also. Circle the points of intersection.
3. Left half of drawing; better solution than the one on the right: discuss with the designer whether a recess as shown is permissible. If so, the hub becomes a body with a uniform wall thickness of 170 to 175 mm, and the hub feeder can be made considerably smaller.
Fig. 133. Padding a hollow shaft.

Proceed in three stages:
1. Draw the section to a scale of 1:1 and outline the machining allowances.
2. Equalise the wall thickness from the bottom upwards (right half of the drawing). In our case a shaped tubular body with \( w = 90 \) mm is obtained. It is also possible that varying minimum wall thickness will occur (for instance 120 mm at the centre of the shaft). The tube should then be continued from this point at 120 mm.
3. Pad the tube, with an equalized wall thickness, on the lines of Figs. 137 and 138 (left side of the drawing).

Fig. 134. Padding an elbow.

Proceed in the three stages:
1. Draw the sections to be padded to a scale 1:1 and draw the necessary machining allowances.
2. Draw radial lines at an interval of 10 mm (around the head), or 100 mm with larger sections. Put the pads at each point from Fig. 138. The initial wall thickness is taken as the wall thickness at the thinnest point in the flange (flange width \( w \text{, min} = 67 \) mm).
3. Use the same method with the other machined flanges.

Fig. 135. Padding a flanged fitting.

Work to the following scheme:
1. Draw the flange to the scale 1:1 and add the machining allowances.
2. Estimate the end fill, and set the intersection (here 70 diameters).
3. Bring the flange (in imagination) to the thickness of the intersection of 70 mm. In this way a body of uniform wall thickness is produced.
4. Insert the center-line of the flange, and divide it by radial lines into sections of 50 mm around the bend (100 mm for larger sections).
5. On the points so obtained start the padding allowance in accordance with Fig. 136. In this instance 10 mm is to be added (difference 70 - 60 = 10 mm, see point 3).
6. Correction of padding allowance: For the above, etc., except that bars and rods have much smaller finishing ranges, and must therefore be given heavier padding allowances. The correction factor is found from Table 24.
7. In most cases the pad curve so obtained can be replaced approximately by a straight line; it is sufficient to determine the starting and finishing points.
8. Pads of this kind produce radiographically sound castings, so that they are only to be used in the way described when high-stressed (and notably stressed) castings subject to strict inspection (100\% radiographic testing) are to be used.
Fig. 136. Padding a Francis turbine wheel. Drawing partly schematic.

The drawing was made partly schematic in order to emphasize the essential points. Such turbine wheels are among the most difficult castings to make, and cannot be produced free from shrinkage cavities unless strict attention is paid to the many junctions and positions where heat will accumulate, especially at the lower flanges.

The following procedure is adopted:

1. Make a reduced sketch of the lower flange, preferably by means of a paper ring on which the pattern of the bladel can be drawn accurately, and which is then opened out.

2. Draw sections to the scale 1:1 at least three levels, adding the necessary machining allowances and a safety margin to allow for irregular contraction.

3. Estimate the sand filled and circle sizes of the blade junctions, especially at the lower positions, where the blades lie very obliquely and therefore close together, the sand filled effect is very pronounced and the circle becomes correspondingly large.

4. Establish the ideal curve of equal wall thickness for the three different levels of cross-section, and insert it in the cross-section. This curve—especially in the upper part of the flange—can in some circumstances lie under the machining allowances. Whether this is to be left or corrected can only be assessed later.

5. Pad the ideal plate so obtained in accordance with Fig. 138. Here the true length (measured obliquely towards the blades and measured around the bend) is to be inserted as the wall height.

6. Corrections: The padding calculated according to Fig. 138 applies to top poured castings and unalloyed steel. If bottom pouring is used partly or entirely, the normal thermal gradient of the casting is impaired and must be compensated by increased padding additions (multiply the values from Fig. 138 by 1.25). In the case of highly-alloyed steels the values from Fig. 138 must also be multiplied by 1.25: (this is an approximate value only—actual data can only be obtained for individual cases by casting trial plates from the steel in question). Examples:

(A) If alloy steel is to be top poured, it is only necessary to multiply by 1.25.
(B) If the alloy steel is to be bottom poured, multiply by 1.25 x 1.25 = 1.56.
(C) If unalloyed or low alloy steel is to be bottom poured, it is only necessary to multiply by 1.25.

7. If the intersection circles are much larger than the wall of the flange, it is recommended unconditionally that the padding should be built up in accordance with the basic rule of equal wall thickness (circles between the blades, a maximum profile in section). These circles can be rounded by means of detachable parts on the pattern. When shrinkage the flange of the blade must be accurately delineated by a joint straight line. In setting the outer circumference must be paid to the corresponding positions of the padding to the blade.

8. The maximum wall thickness of the blade so obtained is determined for the dimensions of the feeder head:

\[ t_{\text{max}} = \frac{W}{2 \times 1.25 \times 1.25} \]

In most cases blind feeders, with a large diameter are obtained. The value is calculated carefully using the modular formula, in order to prevent premature freezing or alternatively an additional accumulation of heat.

9. If the wheel, together with the flange, is top poured (Fig. 125) the intersection must still be rounded in a similar way.

10. The molding method described is expensive in itself, but it can result in a satisfactory round casting, with few draughting castings and a certain risk of crongs.

The problem of the amount by which the diameters of the circles should increase could only be solved "intuitively" at first for unalloyed steels, on the basis of the work by Brinson and Dumas (10) and Srav (11). No values have so far been published for alloy steels.
Increasing the Thermal Gradient in the Casting

Fig. 137. Padding additions after Brinson-Dumas.  

Fig. 138a. Necessary padding additions for steel castings with different wall thicknesses and wall heights.

Fig. 138b. Padding a 25-mm-thick plate of unalloyed cast steel.

Fig. 139. Effect of plate thickness on the size and point of attachment of the pad.