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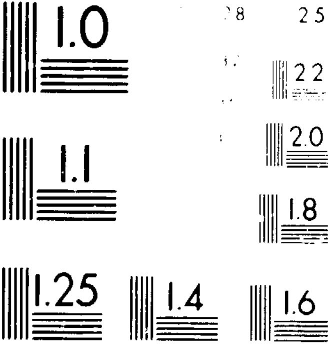

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Manufacture and Quality Estimation of Cast Spare Parts *

by

Z. Górny and J. Marcinkowski **

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TABLE OF CONTENTS

Z. Górny, J. Marcinkowski

MANUFACTURE AND QUALITY ESTIMATION OF CAST SPARE PARTS

S u m m a r y

Among the metal-made parts of machines and equipment, cast elements are very often exposed to overloading under the existing operating conditions. The parts, which get worn more quickly than the other elements, are called spare parts.

Castings are characterized by numerous advantages which result, among others, also from a varied range of the applied metals alloys and an easy formation of a given part in the casting process, compared to f.ex. plastic working or machining. This is the main reason why even the spare parts, usually made by forging, press moulding or rolling, are quite often replaced by castings.

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These advantageous conditions are created, on one hand, by a knowledge of the duties under which a given spare part is working, and on the other by the properties of a casting which result from the type of material used and the casting processes applied.

The main step in the procedure of making a cast spare part is its identification, i.e. determination of the casting material and of the casting process. If a relevant technical documentation containing these data is not available, it becomes necessary to take a decision basing on the collected examples of the already checked applications of the castings working under the described operating conditions.

This paper presents a classification of the cast spare parts, dividing these castings in respect to the operating conditions and the corresponding properties.

Further, some methods of estimating the quality of castings were discussed, and numerous cost indices were given which may be useful for those who will have to take decisions regarding the production of cast spare parts.

The last chapter of this paper relates various casting processes particularly suitable for the production of such castings. A detailed description of the eight castings, differing in respect to the imposed requirements and the materials and processes applied, provides a set of the information indispensable for those who would like to use this technology in order to obtain the cast spare parts.

1. Introduction

Castings used as spare parts in the repairs are generally included into a special group of the parts of machines and eguipment which loose their utilization properties or get damaged much earlier than the remaining elements. In most cases these are:

- parts exposed to friction, abrasion and - as a consequence - rapid wear,
- parts exposed to the effect of aggresive chemical compounds /liquid, gaseous or even solid matters/,
- high-duty parts, damaged as a result of rugged or extra-rugged operating conditions,
- parts damaged as a result of the break-down.

Sometimes, the service manuals of the machines and equipment include a list of the, so called, "parts exposed to a quick wear", which form this basic group of spare parts.

In most cases spare parts are cast elements, in most cases subjected to machining, If it is difficult to reproduce the shape of the non-cast elements /f.ex. forgings, stampings, wire rods, etc./, cast elements may be used as a substitute, since they are much easier to manufacture than parts produced in the process of plastic working. This type of substitution may result sometimes in only partial reproduction of the utilization properties, but at least it enables the machine to start working again. Therefore casting of spare parts is of a greater practical use than it might result from the effectively used number of the cast elements.

The easiest solution is to purchase the spare parts from their manufacturers, directly or indirectly through the supplier of a given machine or equipment. If this is impossible due to various reasons /no production, considerable distance, lack of money, practical restrictions, etc./, it becomes necessary to start the process of manufacturing these parts, which in most cases is not a profitable operation.

The way in which the spare parts are cast is determined by the number of the castings required. Usually these are piece castings or castings made in small-lot production /several or a dozen pieces/, and therefore the technological processes used for their manufacture have to be selected rationally, while the degree of mechanization is rather low. In most cases these elements are cast into sand moulds, sometimes with chills, or into simple hand-operated dies, wherever a higher rate of solidification as well as an appropriate structure and properties are required.

The main task in the preparation of cast spare parts is to identify them, i.e. to determine the material /casting alloy/ in which a given part has been made and a method of its manufacture /i.e. casting and finishing/. In the case of mating parts it is also important to know: the shape and dimensions of a given part, its dimensional accuracy /the admissible dimensional deviations/ and the admissible surface roughness /in parts cast and possibly also machined/. In most cases the technical documentations include this information, full or partial, the relevant data can be taken from the supplier. The information usually states the type of alloy and the heat treatment, if applicable; the data on the casting method are rarely given /f.ex. into sand moulds, dies, under pressure, etc./.

Depending on the information available, the data should be made complete, either fully or in part, to start the operations connected with the manufacture of a casting. This procedure, aiming at a selection of the cast material and casting process, consists in determining: chemical composition /to identify the material/, microstructure and hardness /to evaluate the condition in which the casting is to be used, f.ex. used in the as - cast state or after a heat treatment/, external surface /an evaluation of the casting process and of the surface roughness/ and the like ones; usually appropriate control and measuring devices are necessary here.

When the type of the casting alloy is considered, and it is impossible to find an identical one, the most important factor is to provide an appropriate substitute, and this is an additional vital problem in the process of making cast spare parts.

When it is impossible to use a documentation, when an information about the required alloy is not available and the procedure enabling an identification of the material cannot be carried out, the decision which type of the alloy is to be chosen and which casting process is to be applied should be based on the actual data stating the conditions under which a given part is operating in the whole machine /wear rate, chemical agents, high duty, etc./, and next the alloys assigned for these or similar service conditions should be used.

Finally, the range of the casting materials is to be defined. These will be all casting alloy, i.e. grey cast iron with flake, spheroidal and vermicular graphite, white cast iron, whiteheart and blackheart pearlitic malleable cast iron, carbon and alloy cast steel, nickel and cobalt superalloys and non-ferrous metals alloys, disregarding the alloys of noble metals /platinum, gold and silver/ and the alloys which are not used for castings /f.ex. soft solders/.

In order to sistematize the constituents of the casting alloys /and not only of these alloys/ we can divide them into the following groups:

1. base elements, i.e. those present in large amounts in an alloy and determining its affiliation to a given group,
2. auxiliary elements, i.e. included into the composition of an alloy /alloying elements, admixtures/.

Table 1.1. shows the periodic classification of the elements and marks the base metals /rectangles/ and auxiliary metals /circles/.

The base metals include:

Fe, Ni, Co, Cu, Al, Mg, Zn, Sn, Pb, Cd, Bi, Ti, Mo, Mn, Hg.

The auxiliary metals, i.e. those which can be included into the composition of an allcy but do not form seperate groups, include: C, Si, P, S, Cr, V, W, Sb, Nb, B, Zr, Ta, Hf, Re, N, Y, As, Ag, Be, Te, Ca, Na, Ba, K, Li, Sr, In. There are also rare earth metals i.e. lanthanides, including scandium /Sc/, and thorium /Th/.

Of course, there are many base metals which can simultaneously play the role of the auxiliary ones, and hence we have f.ex. aluminium-copper alloys in which the base constituent /metal/ is aluminium and the auxiliary one is copper; but a reverse situation is also possible, i.e. copper-aluminium alloys.

TABLE 1-1. PERIODIC CLASSIFICATION OF THE ELEMENTS

GROUP	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB			IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
Type Formulas*	R_2O RH	RO RH_2	R_2O_3 RH_3	RO_2	R_2O_5	RO_3	R_2O_7	RO, R_2O_3, RO_2, RO_3, (RO_4)			R_2O	RO	R_2O_3 RH_3	RO_2 RH_4	R_2O_5 RH_3	RO_3 H_2R	R_2O_7 HR	
PERIODS 1	H_1																	He_2
2	Li_3	Be_4											B_5	C_6	N_7	O_8	F_9	Ne_{10}
3	Na_{11}	Mg_{12}											Al_{13}	Si_{14}	P_{15}	S_{16}	Cl_{17}	Ar_{18}
4	K_{19}	Ca_{20}	Sc_{21}	Ti_{22}	V_{23}	Cr_{24}	Mn_{25}	Fe_{26}	Co_{27}	Ni_{28}	Cu_{29}	Zn_{30}	Ga_{31}	Ge_{32}	As_{33}	Se_{34}	Br_{35}	Kr_{36}
5	Rb_{37}	Sr_{38}	Y_{39}	Zr_{40}	Nb_{41}	Mo_{42}	Tc_{43}	Ru_{44}	Rh_{45}	Pd_{46}	Ag_{47}	Cd_{48}	In_{49}	Sn_{50}	Sb_{51}	Te_{52}	I_{53}	Xe_{54}
6	Cs_{55}	Ba_{56}	La_{57}* Lu_{71}	Hf_{72}	Ta_{73}	W_{74}	Re_{75}	Os_{76}	Ir_{77}	Pt_{78}	Au_{79}	Hg_{80}	Tl_{81}	Pb_{82}	Bi_{83}	Po_{84}	At_{85}	Rn_{86}
7	Fr_{87}	Ra_{88}	Ac_{89}†	Th_{90}	Pa_{91}	U_{92}												

* Rare earth series: Ce_{58}, Pr_{59}, Nd_{60}, Pm_{61}, Sm_{62}, Eu_{63}, Gd_{64}, Tb_{65}, Dy_{66}, Ho_{67}, Er_{68}, Tm_{69}, Yb_{70}, Lu_{71}.

† Actinide Series: Th_{90}, Pa_{91}, U_{92}, Np_{93}, Pu_{94}, Am_{95}, Cm_{96}, Bk_{97}, Cf_{98}, E_{99}, Fm_{100}, Mv_{101}, No_{102}.

☐ - base metal

◯ - auxiliary metal

2. Classification of casting materials

Among the various properties of castings, required for the different conditions of their operation, the most popular ones include the, so called, "basic mechanical properties" and the metallographic structure, i.e. an area of the casting or of its part, prepared in an appropriate way for the observations under a microscope. The above mentioned mechanical properties include: tensile strength Rm, yield strength, f.ex. $R_{0,2}$ /i.e. the strength at a plastic strain of 0,2%/, and elongation A. These properties are determined on the test pieces of an appropriate shape, cast separately, together with the casting, or cut out from the casting. The basic mechanical properties additionally include hardness, measured according to the depth of an identation of the ball, cone or pyramid on an appropriately prepared surface of the test piece, or even directly on the casting /Brinell, Rockwell or Vickers tests/.

Of course, the classification of casting materials can also be based on the chemical composition of an alloy, i.e. on the content of the base constituent, of the alloying elements /introduced into the alloy on purpose/ and admixtures /impurities/.

Ferrous alloys, i.e. the alloys in which the base element is iron, are divided into those which contain carbon as an essential addition and into the alloys free of this addition /special alloys, some ferroalloys/. Depending on the form in which carbon is present in the structure /combined, free - i.e. graphite or temper carbon/ and on its content, iron-carbon alloys fall into the following groups: cast iron /pig irons/ and steel /cast steel/.

Cast iron is an iron-carbon alloy /including elements such as: Si, Mn, P and S/ characteristic with this that as a result of the eutectic transformation we get an effect of the precipitation of either graphite /so called "stable system"/ or cementite /so called "unstable system"/. Due to the presence of Si and P, the eutectic point /4,25% C/ shifts to the lower carbon content levels. To estimate the effect of Si and P /possibly also of Mn or S in the cast iron in which the effect of all the elements is calculated in terms of carbon/, we use the notion of the "eutectic saturation point" Sc or "eutectic carbon equivalent" Ec.

The white cast iron contains in its structure cementite /apart from ferrite and pearlite/; due to elevated hardness, it is sometimes called hardened cast iron. The simultaneous presence of cementite and graphite gives the, so called, "mottled" cast iron. On the other hand, when the free cementite is not present in the structure, the precipitations of graphite occur, and the fracture of cast iron becomes grey. Depending on the shape of the spatial graphite precipitates, the, so called, "grey cast iron" may have flake, spheroidal /nodular/ and vermicular /compact/ graphite; the processes of inoculation, which change the structure of cast iron, enable the obtention of grey cast iron, although - according to the chemical composition - it should be white or mottled cast iron. This grade of cast iron is called inoculated or Meehanite cast iron from the name of the company which first acquired a patent for this process.

The content of alloying elements in the white and grey cast iron /with flake, spheroidal or vermicular graphite/ gives the notation of the alloy cast iron /high-alloy, medium-alloy and low-alloy/. In respect to which of the alloying elements dominates, we distinguish here cast iron with chromium, silicon, manganese, nickel, copper, molybdenum, antimony, titanium, vanadium, phosphorus, tin or cobalt. The alloy cast iron usually contains more than one alloying element, and so f.ex. chromium cast iron quite often also contains additions of Ni, V, Ti, Mo, Cu, W or Al /as single additions or several at the same time/; silicon cast iron contains Cr, Mo; manganese - Al, Si, Cu, Ni; nickel - Cr, Ti, Mo, Cu, B, Mn, Si; copper - Cr, Ni, Ti; molybdenum - Cu, Cr, V, Ti, Cr; titanium - V.

In respect to the structure, to classify the metallic matrix in the as-cast state or after the heat treatment we use - appart from the shape of graphite, such structural constituents as ferrite, pearlite, ledeburite, cementite, austenite, martensite, bainite or troostite.

The malleable cast iron is obtained as a result of the heat treatment which consists in either decarburization /whiteheart malleable cast iron/ or graphitization of cementite to the, so called, "temper carbon" /blackheart malleable cast iron/; in the case of an incomplete graphitization we obtain the, so called, "pearlitic malleable cast iron". Malleable cast iron may also contain some alloying elements which enable an obtention of the required properties.

Cast steel is a corresponding form of steel assigned for castings, while steel occurs in one of the plastic-worked forms, f.ex. forged pressed, rolled, drawn, etc.

Cast steel is an iron-carbon alloy /up to about 2% C/, containing also other elements; carbon /unalloyed/ cast steel is the one which contains up to: 0,9% Mn; 0,5% Si; 0,3% Ni; 0,3% Cr; 0,2% W; 0,2% Co; 0,2% Cu; 0,1% Al; 0,05% Mo; 0,05% V or 0,05% Ti.

Depending on the required mechanical properties and the content of phosphorus and sulphur, low-carbon /up to 0,25%/, medium-carbon / 0,025 up to 0,60% C/ and high-carbon / 0,60% C/ cast steel may be of a common, elevated and extra high grade.

The classification of alloy cast steel usually emphasizes the alloying element, f.ex. manganese, chromium, manganese-silicon, chromium-molybdenum, chromium-nickel, chromium-manganese-silicon, manganese-silicon-molybdenum, as well as its designation, f.ex. cast steel constructional /for performance at normal or elevated temperatures/, corrosion-resistant, stainless, acid-resistant, heat-resistant, for tools, magnets, /metallurgical/ rolls, or wear-resistant.

The same, as in the case of cast iron, structural constituents determine the classification of carbon or alloy cast steel in the as-cast state or after a heat treatment.

Ferrous alloys also include some nickel and cobalt alloys, in particular the, so called, "superalloys". Their structure is quite often similar to that of the alloy cast steel with a high content of the hard and wear-resistant carbides. In the specifications of these alloys there are numerous trade names and designations which make their rational classification much more difficult.

In the classification of copper alloys we take into consideration these alloying constituents which exert an essential influence on the structure /internal constitution/ and properties of a casting. Such alloying constituents are: tin- and the copper-tin alloys are denominated as tin bronze or, in short, bronze, aluminium /aluminium bronze/, nickel /nickel bronze/, lead /lead bronze, leaded copper/, silicon /silicon bronze/, beryllium /beryllium bronze/, cobalt /cobalt bronze/, manganese /copper-manganese alloys/, zinc /brasses/.

Sometimes the second alloying addition to copper is also emphasized, and thus we have f.ex. copper-tin-zinc alloys, commonly known under the name of gunmetals.

Brass is a copper-zinc alloy containing the latter element in an amount above 15-20%; a lower zinc content have tombacs /red and semi-red brasses/.

We distinguish common brasses, which are CuZn alloys possibly with a small addition of lead /up to about 1%/, and special brasses which, appart from zinc, contain other alloying elements, usually emphasized in the name, f.ex. manganese /manganese brass/, silicon /silicon brass/, tin /tin brass/, nickel /nickel brass/, etc.

Table 2.1. gives a list of other groups of alloys which need no comments, although in some countries, especially the English-speaking ones, numerous trade names and designations make it much more difficult to put into classification these alloys in respect to their alloying or structural constituents.

3. Classification of operating conditions

The operating conditions of the castings working as parts of machines and equipment or operating individually /f.ex. cast pipes/, this also including spare parts, stimulate a necessity of using the materials of such properties which enable the longest possible time during which they preserve their utilization properties. To facilitate a comparison of the performance of different casting materials under given operating conditions, the evaluation has to account for some specific properties or resistance levels which would, on one side, characterize the required operating conditions, and on the other, the strength of the material. There are numerous properties which determine a given material in relation to its operating conditions; the main ones include: mechanical properties, magnetic properties, thermal properties, resistance to the action of chemical agents or wear resistance.

Apart from Rm, $R_{0,2}$, A and hardness, the mechanical properties also include compression strength, bending strength, torsional strength, and shear strength - all of them determined on appropriate test pieces. A set of the different types of strengths /Fig. 3.1./ determines the name used for the mechanical properties. The above mentioned mechanical properties may be determined at both ambient temperature /usually 20°C/ or at elevated temperatures /up to even several hundred °C/, or at the sub-zero temperatures /usually to -40 or - 60°C/, depending on the operating conditions.

Special mechanical properties /resistance to mechanical loading/ are required in the case of an application at elevated temperatures. Then we have to ensure that the material is heat resistant, i.e. preserves at an appropriately high level its mechanical properties at a temperature up to 1000°C in relation to the same properties

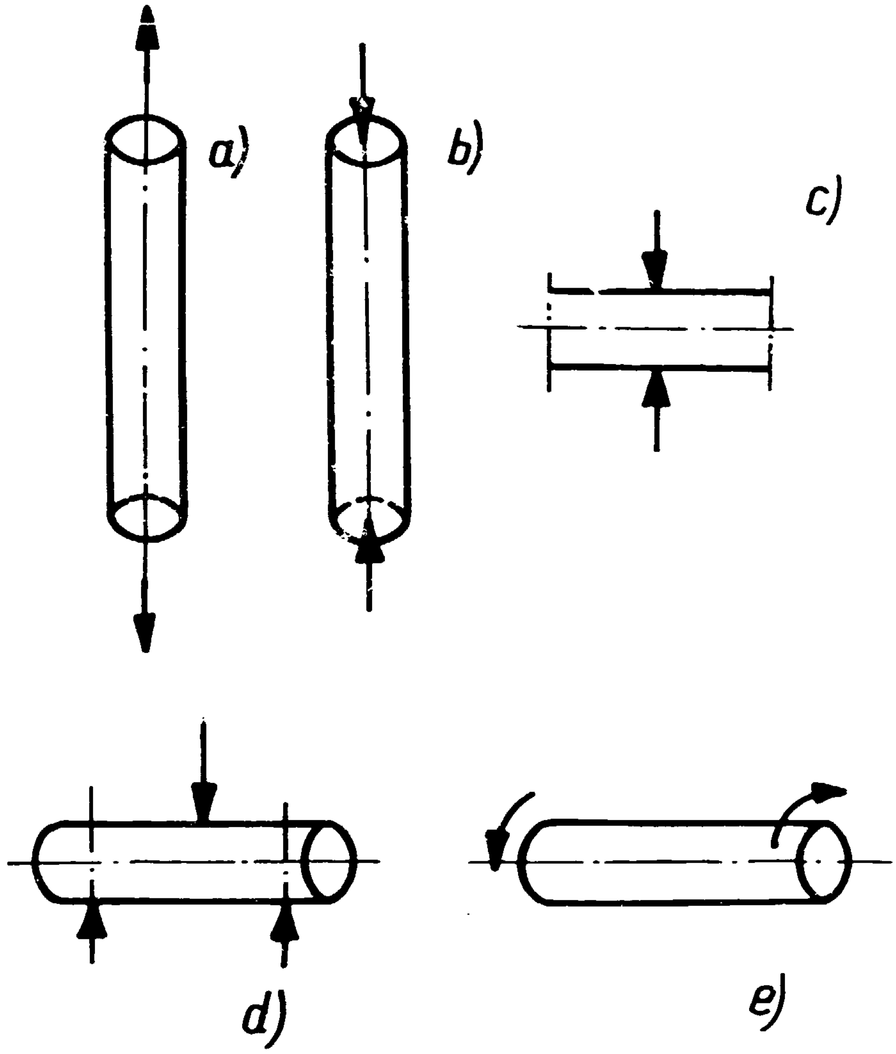

Fig. 3.1. Basic kinds of simple loading;
a - stretching; b - compression;
c - shear; d - bending; e - torsion

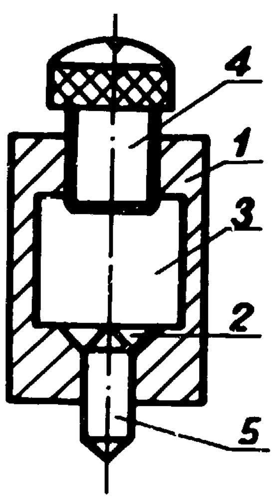

Fig. 5.2. A schematic drawing of the Poldi hardness tester for comparative measurements;
1 - body; 2 - hole for reference plate; 4 - crew for fastening the refer nce plate; 5 - identer /bilateral cone/

revealed at ambient temperature. In a similar way, the property called creep resistance has to ensure the preservation of appropriate relative values up to a temperature of 1000 °C. Alternating elevated temperatures are typical of the, so called, thermal shock.

One of the basic mechanical properties is impact strength determined on the notched specimens /with an identation/ or on the unnotched specimens. This is a measure of the work required for a failure of the specimen and referred to the fracture area; the impact strength is thought to characterize the ability of a given material to resist the mechanical loads of an impact-like nature. In the case of vibratory mechanical loads /alternating in time and of a high (of some hundreds) frequency Hz/, an important characteristic of the material is its damping capacity /f.ex. the cast iron with flake graphite is much better than cast steel/. With alternating loads of a lower frequency we have mechanical fatigue strength /in most cases the resistance to the alternating torsional or bending loads, or flexural-torsional loads/. In the case of permanent loads, lasting for hundreds, thousands, ten and hundred thousands hours, we have the, so called, "creep strenght" or tensile strength /f.ex. pressure vessels/.

Among the magnetic properties, required sometimes, we usually deal with the properties such as: magnetic permeability or coercive force, and thus the physical properties typical of magnets and electromagnets. Another property is lack of the magnetizability /non-magnetizability/, very important in the work under an effect of the magnetic field.

Thermal properties include thermal conductivity /analogical but not identical is the electric conductivity, its inverse being the electric resistance/.

Among the numerous types of the resistance to the effect of aggressive chemical compounds, the most popular is corrosion resistance /resistance to the action of some determined matters/. Similar resistances but determining different operating conditions are erosion resistance /a chemically active agent but at the same time mechanical abrasion/ and cavitation resistance, typical of the elements working in hydraulic systems where the wear proceeds at a quicker rate due to the presence of gas bubbles swirled in the liquid medium /f.ex. air bubbles in water/.

A specific example of the attack from the environment is the formation of scale, i.e. of the film of oxides on the surface of the metal elements operating at elevated temperatures; therefore in some special cases we can have a notion of the scaling resistance. Scaling occurs very often when there is a movement of the gases at an elevated temperature /f.ex. exhaust gases/, and then we can speak about the resistance to the /corrosive/ action of the hot gases.

Numerous castings, this including also spare parts, are working under the conditions which promote their mechanical wear due to abrasion; this mainly refers to the mating parts which are moving against each other /f.ex. shaft and bearing, piston and cylinder, etc./. In such cases the casting material must have a high abrasion or wear resistance. In the case of slide bearings we sometimes speak about the sliding properties of the bearing material, characteristic with both low wear and low coefficient of the sliding friction; this obviously regards the cases of an insufficient lubrication and mitigated solid or solid friction /without the separating film of lubricant/.

An application of the nuclear technique is combined with certain requirements concerning protection against the radiation of electrones and γ rays; this also refers to the alloy itself which has to be characterized by an extra high purity, free from any trace elements /admixtures/.

One of the requirements, imposed rather rarely, is the ability to obtain surface hardening of an external layer of the casting or of its cavity in relation to a considerably less hard internal part, or f.ex. the enamelling power, i.e. an ability to receive a film of the enamel as a coating finishing the cast surface. This refers to the grey iron castings. In a similar way, sometimes it is required to provide a power of the anodic oxydation /aluminium alloys/ or for an application of the electrolytic coatings /f.ex. nickel or chromium plating of copper alloys/.

An important characteristic, required in the case of hydraulic parts and especially the high-pressure ones, is the, so called, "tightness" examined on the special test stands and checked as a tightness for compressed air after immersion in a water bath or as a tighteness for water under pressure.

To illustrate the requirements imposed to the castings of various scopes of application, Table 3.1. gives an exemplary attempt of correlation: operating conditions, type of casting and its material.

4. Classification of cast parts

Irrespective of the accepted criterion of a division of the cast parts, it seems advisable to speak only about the most popular ones, since it is neither possible nor useful to mention all of them. The dominating operating conditions were accepted as a criterion of the division, i.e. the conditions originating from both the applied loads and from an effect of the environment, or resulting from some special requirements imposed into these parts.

There are following classes of cast parts:

I. Fixed elements

II. Fixed elements mated with the other ones

III. Elements performing plane-reciprocating motion in contact with the fixed elements and at ambient temperature

IV. Elements used as fixtures or pedestals

V. Elements rotating around their own axis bearing an extra load on their perimeter

VI. Elements used for the transmission of a rotary motion or fixed but promoting a mutual rotation of the mating parts

VII. Elements exposed to bending and compression, fixed or performing small movements around the axis of rotation.

VIII. Elements in which friction of the mating parts is used for checking of the rotary motion.

IX. Elements exposed to the effect of gases flowing at elevated temperatures

X. Rotating elements loaded by the centrifugal forces and transporting liquids or gases

XI. Fixed elements used in the transport and distribution or storing of liquids and gases

XII. Elements used for rolling of sheets, rubber, etc.

XIII. Fixed elements exposed to the pressure of liquids or gases

XIV. Elements used for shaping of other metallic elements

XV. Elements of the electro-technical and welding equipment

XVI. Elements used for the determination of weight or for an additional loading of the equipment

XVII. Elements exposed to severe friction, abrasion and impacts

XVIII. Castings used in household and as ornaments

I	Fixed elements which are slide bearings of shafts, spindles, etc.

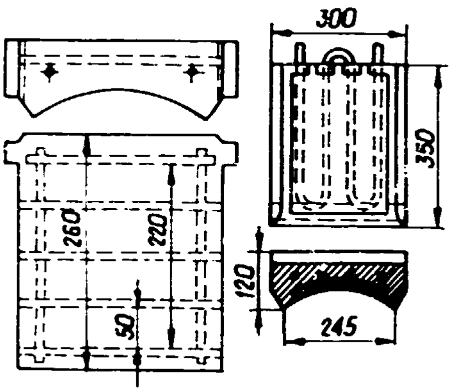

Fig.I.1. Bearing for rolling mill with steel coil

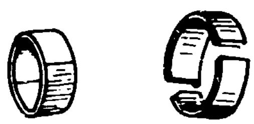

Fig.I.2. Bearing half-sleeves

a/ b/ c/

Fig.I.3. Bearing halfsleeves
a - front main; b - central main; c - rear main

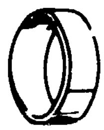

Fig.I.4. Camshaft bearing bush

This group includes slide bearings of various types, bearing sleeves, bearing bushings and half-sleeves of bearings.

Here it is necessary to provide good wear resistance, good sliding properties, and in some cases also the preservation of these properties under the conditions of an insufficient lubrication /mitigated solid friction instead of fluid friction/.

Depending on the operating conditions, we distinguish the alloys of a low hardness /for bearing bushes/-these are generally Sn or Pb alloys, more rarely Cd or Al alloys-nowadays cast in a continuous process on a steel or brass strip as well as on a layer of bronze or cast iron /the bracking bearing bushes/, and the materials of a higher hardness /bearing sleves/ made in most cases of tin bronzes, more rarely of grey cast iron.

II	Fixed elements mated with the other elements and performing a plane-reciprocating motion at ambient temperature

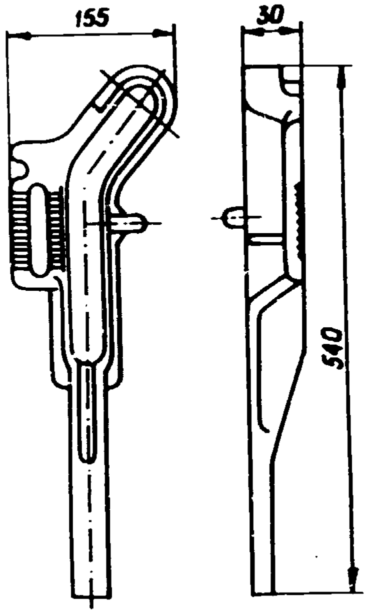

Fig.II.1. Yoke

These elements are additionally exposed to the atmosphere of hot gases /cylinder sleeves, valve guides, valve seats/.

The elements operating at ambient temperature should have a good abrasion resistance, with an elevated temperature and the effect of hot gases it is additionally necessary to ensure good resistance to corrosion, sealing and thermal shocks.

In the first case we use the abrasion-resistant grey cast iron, sometimes surface hardened; carbon cast steel or bronzes are used less often. In the second case we use low alloy grey cast iron /cylinder sleeves/ and alloy cast iron, alloy cast steel, or even super-alloys /valve seats/.

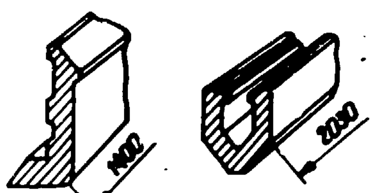

Fig.II.2 Guides

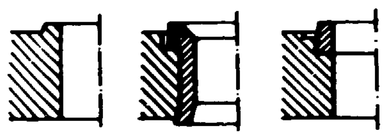

Fig.II.3. Valve seats

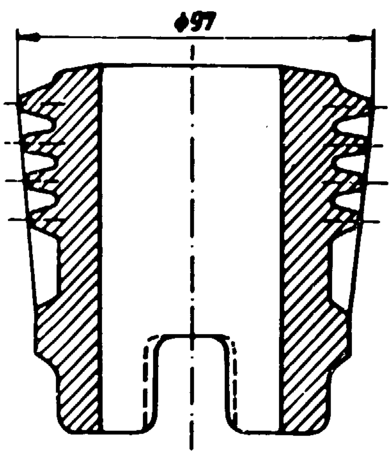

Fig.II.4. Cylinder of an compressor

III Elements performing plane-reciprocating motion in contact with the fixed elements and at ambient temperature

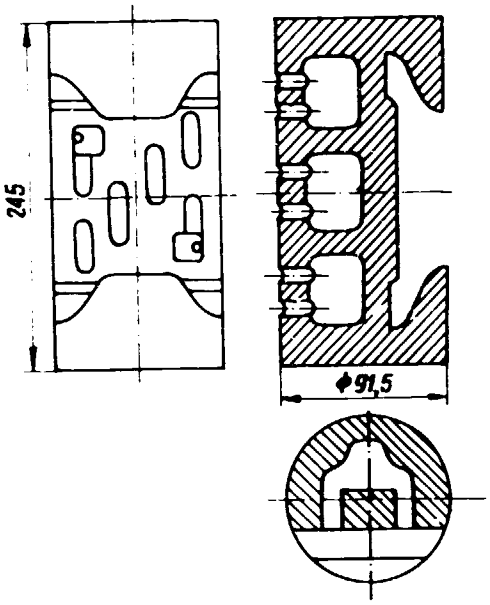

Fig.III.1. Slide

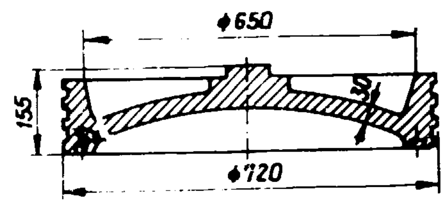

Fig.III.2. Hydraulic piston

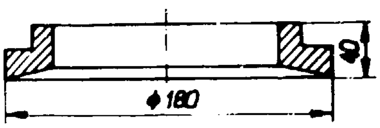

Fig.III.3. Ring

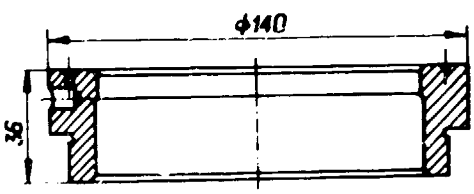

Fig.III.4. Slide piston

These elements are made of hardened cast iron and high-carbon cast steel. The pistons of I.C. engines, additionally exposed to the effect of elevated temperatures and hot gases are made of Al alloys /Al-Si; Al-Si-Cu/; less often of cast iron or alloy steel.

A separate group form piston rings and the like elements made of grey cast iron, less often of steel or cast steel.

IV	**Elements used as fixtures or pedestals, such as base plates, frames, trestles, benches, pillars, holders, floors, housings, etc.**

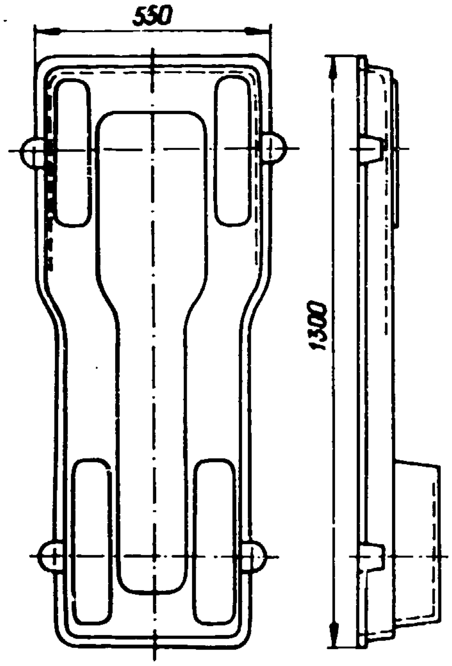

Fig.IV.1. Bed-plate

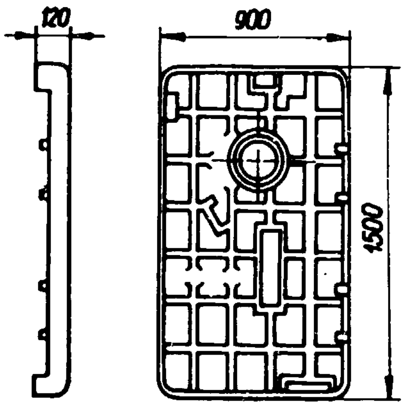

Fig.IV.2. Bed

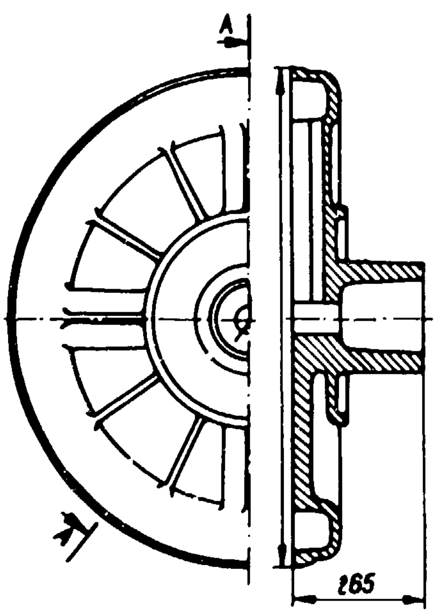

Fig.IV.3. Drop end

Generally speaking, parts of machines and equipment operating at ambient temperature and under normal conditions are made of grey cast iron and cast steel; for I.C. engines malleable cast iron, Al alloys and sometimes also Mg alloys are applied, whenever a reduce in the weight of a car is expected.

When the element contacts aggressive substances, acid-, alkali-, or salt-resistant cast irons or alloy cast steels are used; stainless cast steel is also applicable sometimes.

A specific example of the mounting art are fixed nuts in large hypoid gears /movable screw/; they are made of Cu alloys, sometimes - but less often - of grey cast iron. Movable nuts in some mobile screw joints are cast in malleable iron.

IV	Elements used as fixtures or pedestals, such as base plates, frames, trestles, benches, pillars, holders, floors, housing, etc.

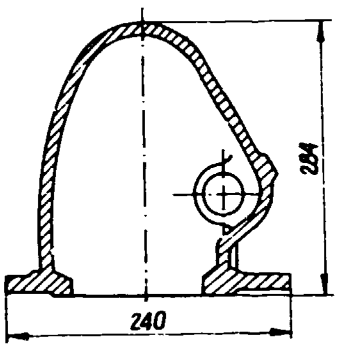

Fig.IV.4. Housing

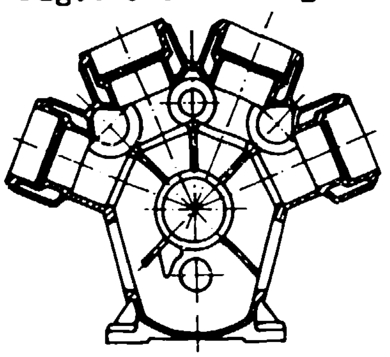

Fig.IV.5. Compressor casing

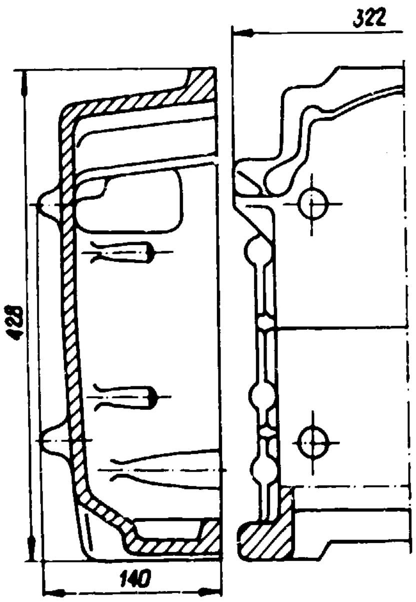

Fig.IV.6. Oil sump

The bodies of I.C. engines, called cylinder blocks, are cast in Al alloys /motor-cars/, or in cast iron, or low-alloy cast steel. To facilitate fixing of various elements in the bodies or cases, special flanges are made, usually of the same material.

Housings and other castings used as elements of the office equipment /typing machines and computers/, optical and precision equipment /field-glasses, epidiascopes, projectors, cameras/ and tools /drilling machines, saws/ are cast in Al or Mg alloys, similarly as frames of the racing bicycles.

V	Elements rotating around their own axis bearing an extra load on their perimeter

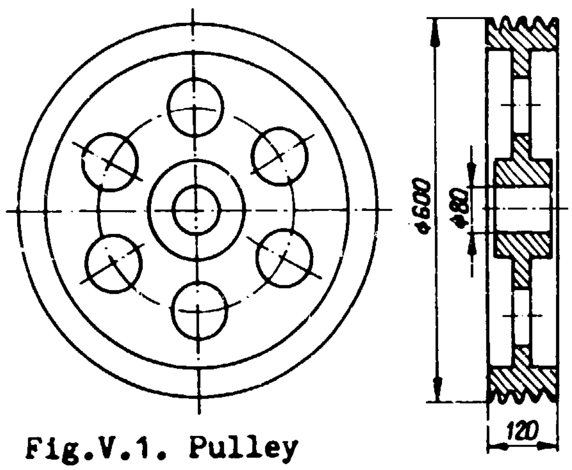

Fig.V.1. Pulley

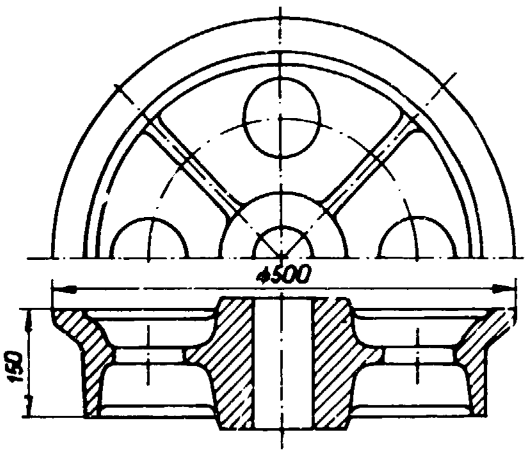

Fig.V.2. Drive wheel

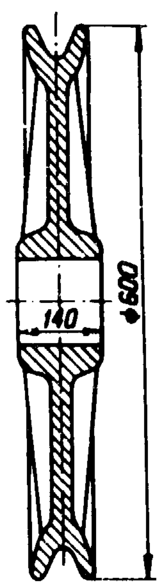

Fig.V.3. Rope sheave

There are various types of wheels. High mechanical properties are often required here /bending strength, torsional strength, fatique strength/. Belt pulleys, sheaves and rope pulleys are usually cast in grey, sometimes malleable, cast iron. In some special cases, when extra high loads are applied, we use carbon cast steel or low-alloy cast steel.

The wheels of trucks, cranes, etc. are exposed to a quick wear /high unit thrusts/ and impacts, and they are cast in grey iron or steel.

A special category of wheels are the toothed wheels which in the mating pairs form the, so called, toothed gears used for the transmission of a rotary motion from one parallel to another /cylindrical wheels/ situated either at an angle /tapered wheels/ or oblique /hyperboloidal gears/. Toothed wheels should have a high wear resistance /mesh/, and they are made of grey cast iron, low-alloy cast iron, carbon cast steel and constructional alloy cast steel often subjected to a heat treatment.

V Elements rotating around their own axis bearing an extra load on their perimeter

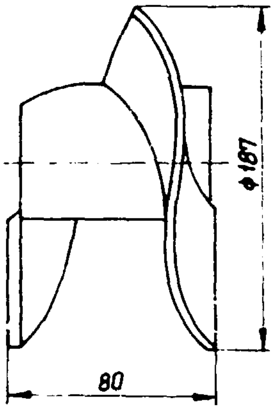

Fig.V.3. Worm

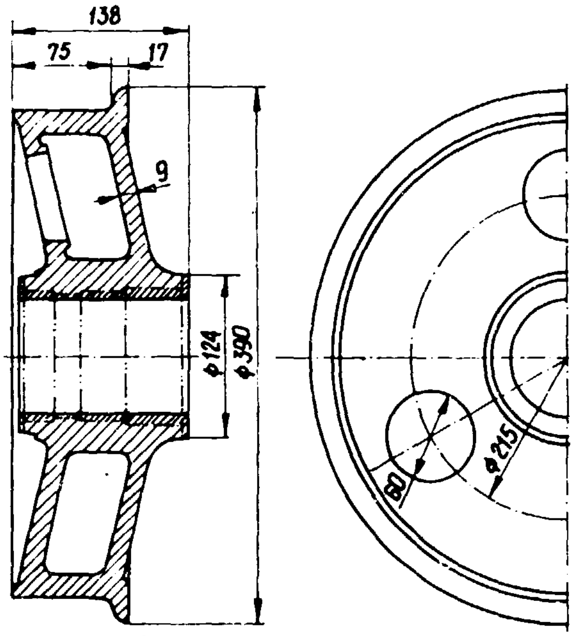

Fig.V.6. Wheel for the mine truck

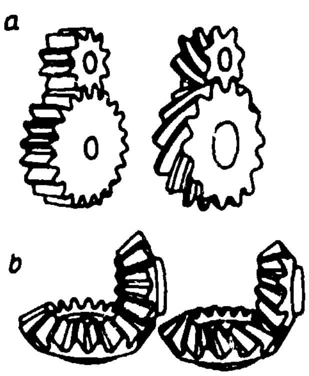

Fig.V.8.Toothed gear
a-cylindrical
b-angular

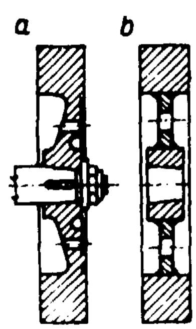

Fig.V.9. Flywheel
a-cast
b-welded

When exposed to a special effect of the environment, these parts are made of another alloy cast steel/f.ex. stainless cast steel/, Cu, Zn or even Al alloys.

In a toothed gear which enables a transmision of the rotary motion between the axes perpendicular to each other the worm and the worm wheel are exposed to a quicker wear than the toothed wheels. The worm gears are usually made of Cu alloys /tin bronzes with phosphorus, aluminium bronzes/; in some special cases of grey cast iron or cast steel.

A separate group form flywheels. They are characterized by a relatively large weight, and when they are spinning the tensile loads are formed. They are made of grey cast iron, and in the case of extra high loads of the cast steel.

Wheels of tracklaying vehicles or goods vehicles are cast in Al and Mg alloys /reduce in weight/, or in carbon and alloy cast steels for higher loads.

The hub, which is a movable element used for fixing the stationary axle, may also be included into the group of wheels; hubs are cast in malleable cast iron or cast steel.

VI Elements used for the transmission of a rotary motion or fixed but promoting a mutual rotation of the mating part

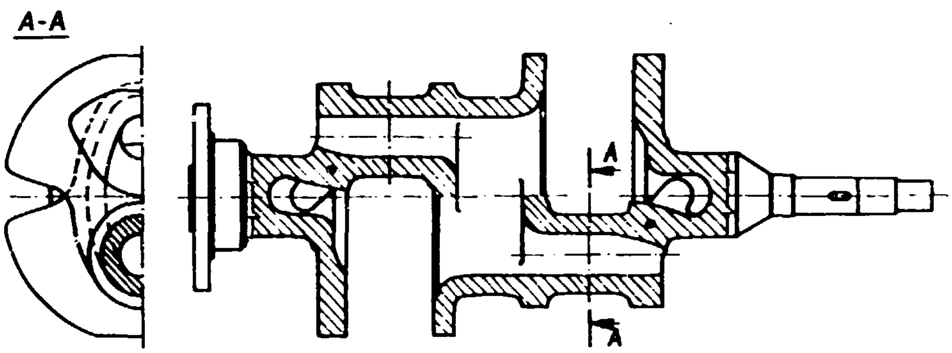

Fig.VI.1. Crankshaft /cast iron/

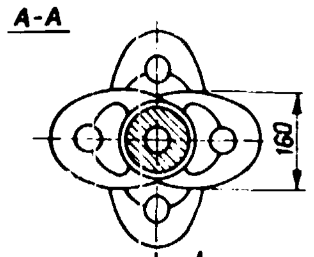

Fig.VI.2. Crankshaft

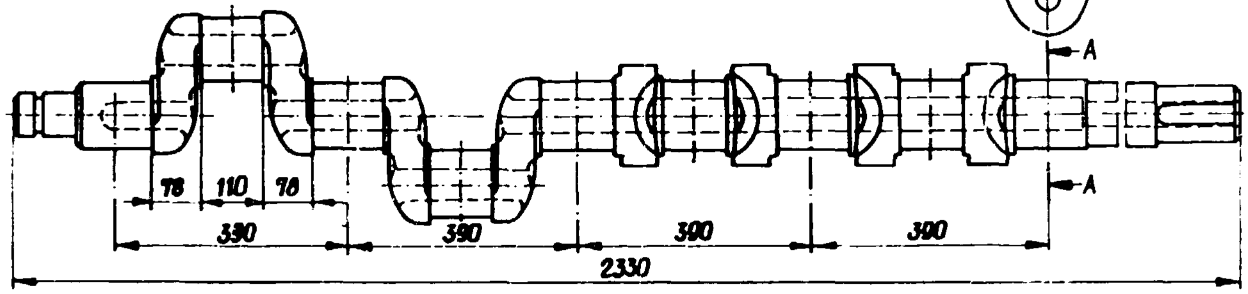

Fig.VI.3. Crankshaft for an ammonia compressor

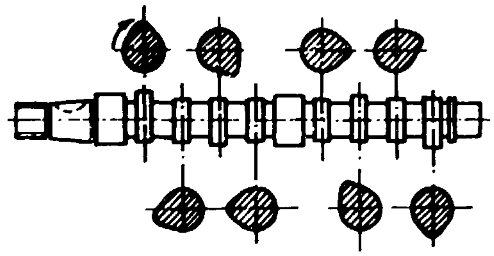

Fig.VI.4. Cam-shaft

In the case of certain I.C. engines and compressors, there are crankshafts cast in grey cast iron with spheroidal graphite or with flake graphite.

The casting process is applied much more often in the case of cam-shafts for I.C. engines, the s.g. cast iron and low-alloy cast iron with flake graphite being used here. Apart from the torsional loads, these shafts are exposed to a quick wear and impacts /from the cam followers put in motion by the cam noses/.

VI	Elements used for the transmission of a rotary motion or fixed but promoting a mutual rotation of the mating part

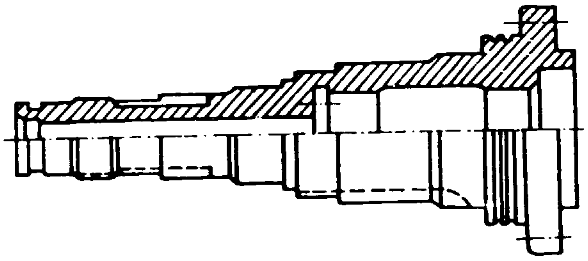

Fig.VI.5. Spindle for the lathe

Spindles which are pipe shafts, are mainly exposed to torsion; moreover they should have a good damping capacity and are usually made of grey cast iron; in some special cases of cast steel or steel /cast-welded, forged/.

Pins /usually the cylindrical ones/ are exposed not only to torsional loads but also to bending loads and impacts. They are made of steel or constructional cast steel; rarely of cast iron, Cu alloys or the like materials.

Numerous other shafts and the elements of a similar shape and function are made of grey and malleable cast irons, constructional cast steel, and very rarely of Cu, Al or Mg alloys.

VII	Elements exposed to bending and compression, fixed or performing small movements around the axis of rotation

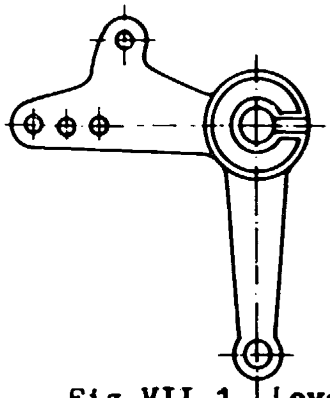

Fig.VII.1. Lever

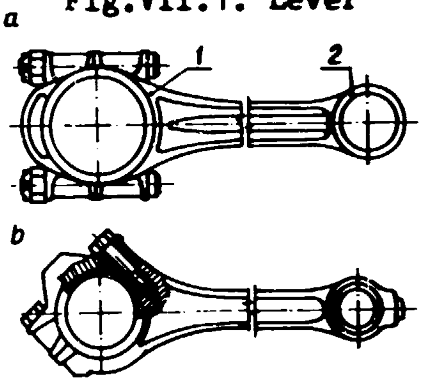

Fig.VII.2.Connecting-rods

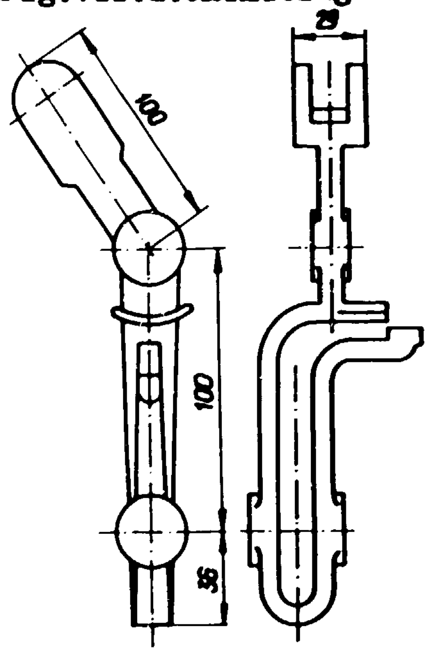

Fig.VII.3. Handle

There are elements such as f.ex. levers, brackets, forks, crosses, connecting rods, cranks, certain tools and pushers, made /depending on their size and reading rate of/ malleable cast irons, and constructional cast steel. In the case of an additional effect of temperature and the presence of gases or aggressive media, high alloy cast steel, super-alloys or Ti and Cu alloys are applied. When these elements are used for I.C. engine vehicles and aeroplanes, Al and Mg alloys are also applicable.

Similar materials are used for the elements exposed to bending and tension, such as f.ex. chain links, holders, handles, grips, ferrules, etc. Chain links are made of malleable cast iron or cast steel /alloy cast steel when the medium is aggressive/; grips, handles and ferrules are cast in malleable iron furniture - in Cu alloys /brasses/ or in an inflammable medium /f.ex. vapours of benzene, petrol, etc./ the so called, "non-sparking" tools made of Cu alloys /silicon bronzes/ are used.

VIII	Elements in which friction of the mating parts is used for checking of the rotary motion

These are elements such as barrels, disks and brake shoes, or for an elastic transmission of the after - axial rotary motion /clutch plates/.

In both cases good wear resistance at a relatively high coefficient of friction is required.

Grey cast iron with flake graphite and possibly an elevated content of phosphorus is used /f.ex. brake shoes for railway cars/.

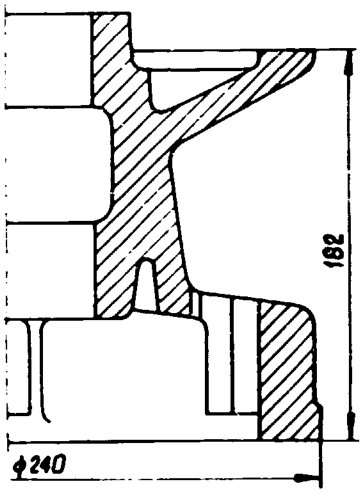

Fig.VIII.1. Brake drum

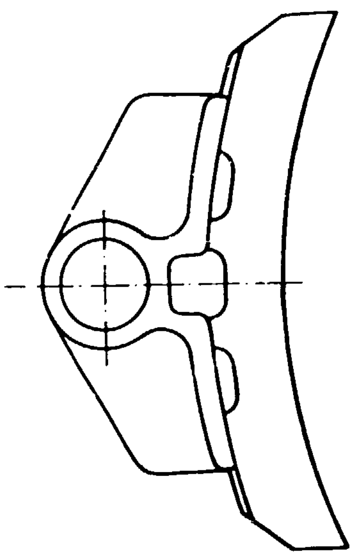

Fig.VIII.2. Brake shoe

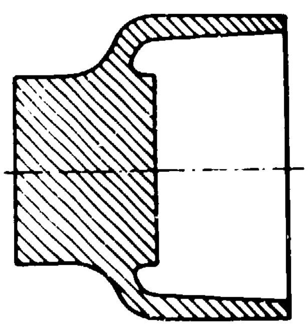

Fig.VIII.3. Brake back plate

IX Elements exposed to the effect of gases flowing at elevated temperatures

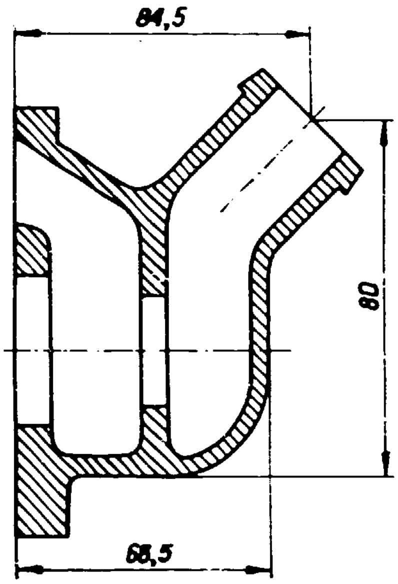

Fig.IX.1. Pipe stub

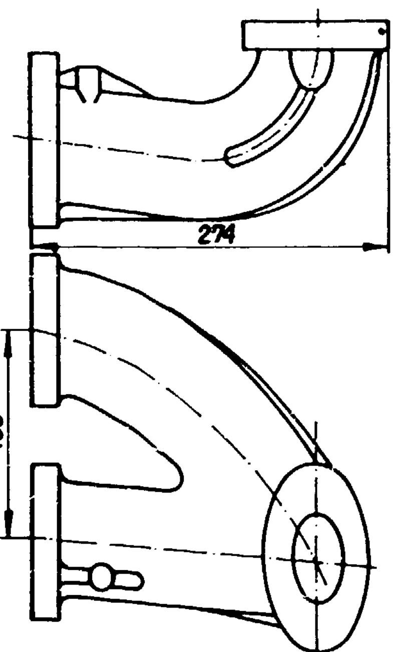

Fig.IX.2. Exhaust conduit

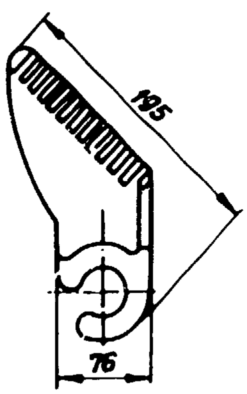

Fig. IX.3. Grate bar

These elements, used for taking off gases from the machines and equipment such as f.ex. connector pipes or exhaust pipes of the I.C. engines, are made of the heat-resistant, alloy cast iron /with chromium or aluminium/, less often of the heat-resistant cast steel.

Similar fixed elements used for protection, reinforcement or separation of equipment, such as f.ex. furnace doors, ash pits, grates, etc. are made of grey cast iron, heat-resistant cast iron /Cr, Al/, carbon and alloy cast steel.

In reaction engines and rocket motors there is a set of the elements which contact the hot gases of high relative speed; a typical example are the truje'res made of the high-alloy cast steel, superalloys or Mo alloys; the other elements working in the medium of flowing gases are sometimes made of Ti alloys.

X	Rotating elements loaded by the centrifugal forces and transporting liquids or gases

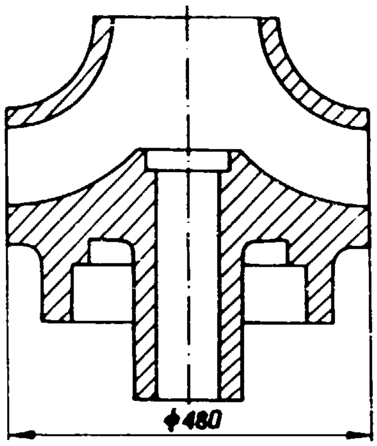

Fig.X.1. Rotor

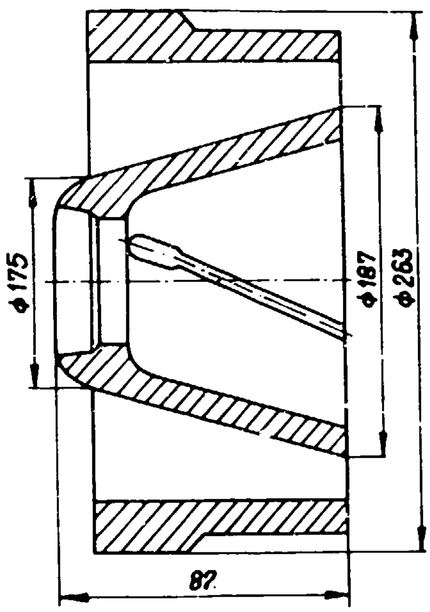

Fig.X.2. Guide wheel

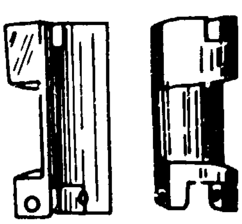

Fig.X.3. Vane guide wheel for turbine

These are elements such as f.ex. rotors and steering wheels of the turbo--machines, water, steam or internal combustion turbines, air-craft jet turbine engines, water pumps and the rotors used in chemical industry, rotors of compressors, etc.

In the case of water turbo-machines the rotating elements are made of grey or low-alloy cast iron, constructional, carbon and low-alloy cast steel, Cu alloys. In the medium of aggressive water alloy cast steel or stainless cast steel is used.

For the rotating elements of steam and internal combustion turbines and turbo jets we must use the materials of elevated mechanical properties, such as high-alloy cast steel, heat--resistant superalloys or Mo alloys.

The rotors of the air turbo-machines are also made of Al and Mg alloys to ensure a reduce in the weight of the rotating elements.

X Rotary elements loaded by the centrifugal forces and transporting liquids or gases

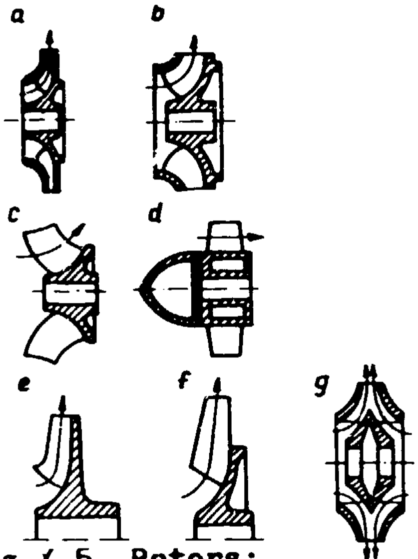

Fig.X.5. Rotors; a-centrifugal; b-diagonal; c-open; d-torsional; e-unilateral open; f-binary open; g-two-stream

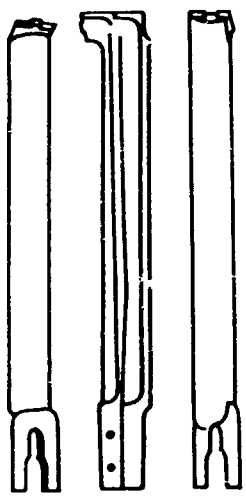

Fig.X.6.Vane for turbine wheel

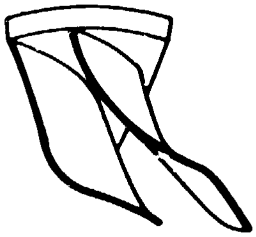

Fig.X.7.Vane for turbine wheel

A specific case are the hydraulic power converters in which the rotating elements are made of Al alloys.

Another atypical example is the construction of rotors and steering wheels which use the blades manufactured separately, i.e. either cast in the precision casting processes or forged in Co-Mo alloys /stellites/ and mounted in steam and gas turbines. Blades are also used in the throwing rotors of shot blasting machines in which they are exposed to a particularly severe wear due to the presence of the shot. Such blades are made of the abrasion and wear--resistant grey and white cast iron as well as of the alloy cast steel.

Propeller screws, used in the drive system of ships, are made of Cu alloys /manganese brasses/ or of stainless cast steel /panels of the adjusting screws, in general/.

XI Fixed elements used in the transport and distribution or storing of liquids and gases

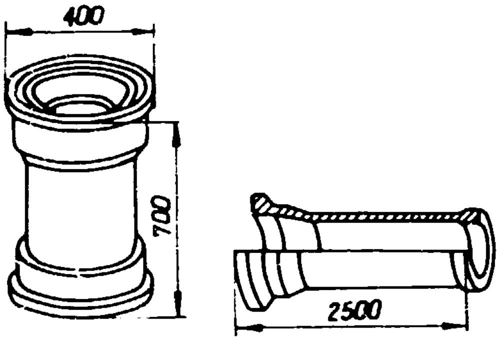

Fig.XI.1. Pipes

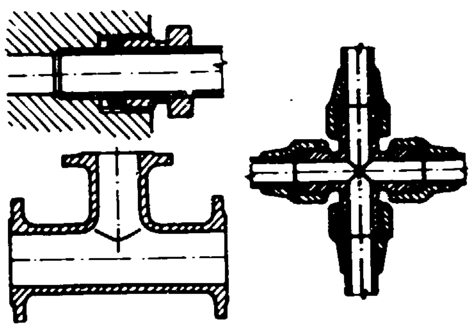

Fig.XI.2. Pipe fitting

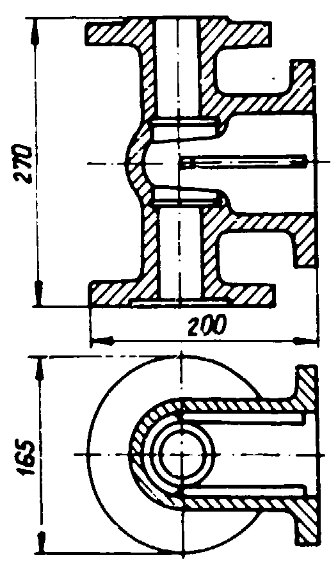

Fig. XI.3. Valve barrel

These are elements such as pipes, connecting links, fittings, elbows, valve bodies for pumps, turbines, etc.

Water-main and gas pipes as well as their fittings and connecting links, used for the distribution of municipal water or fuel gas, are called pressure pipes, since the water or gas flowing in them are kept at a pressure of up to even 300 MPa. These parts are made of grey cast iron with spheroidal or flake graphite. In large mains systems steel pipes are used. Pipes for the sewage disposal /storm sewage/ are made of the cast iron with flake graphite.

Pipes, connecting links, elbows, distribution tanks, elements of the gas, water and sewerage system as well as the cast parts of the sanitary elements are made of the cast iron with flake graphite.

Similar materials are applied for parts of the boilers for central heating and heaters, the latter ones being also made of Al alloys.

On the other hand, parts of the household equipment, such as - valve bodies, passages, tapers, etc. are made

XI	Fixed elements used in the transport and distribution or storing of liquids and gases

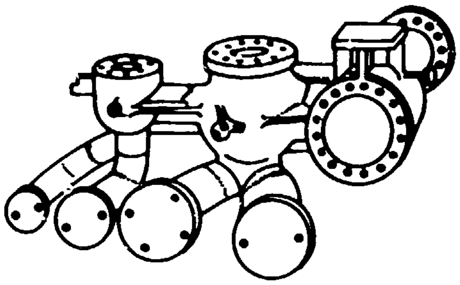

Fig.XI.5. Pipe connection

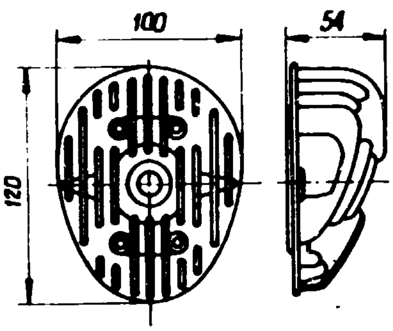

Fig.XI.6. Cylinder head

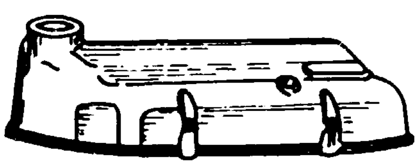

Fig.XI. 7. Cylinder head

of Cu alloys /brasses/ or of malleable cast iron.

Sanitaries, such as - bath tubs, sinks, etc., used after enamelling, are cast in the grey iron with flake graphite, similarly as the equipment used in the chemical industry; the only difference is in the type of the enamel coating applied.

Elements of the industrial steam machines are made of Cu alloys, low--alloy cast iron, carbon and alloy cast steel. When the elements are exposed to the effect of aggressive substances, alloy cast steel is used /stainless cast steel, acid- and alkali-resistant cast steel and Pb alloys/.

Elements of the high-pressure hydraulics /working pressure of up to 6000 MPa/, such as f.ex. bodies of valves and distributors, require a very compact structure /tightness/ and are usually made of the grey cast iron with flake or spheroidal graphite as well as of the low-alloy cast iron or steel.

Heads or blocks of heads are made of Al alloys; less often of cast iron or low-alloy cast steel.

XII Elements used for rolling of sheets, rubber, etc.

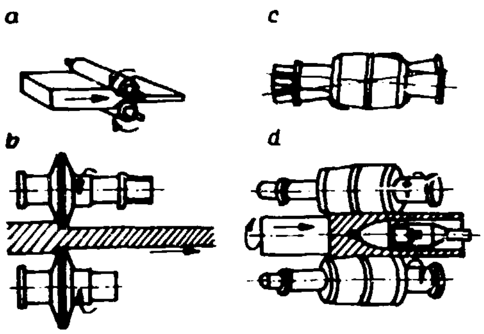

Fig.XII.1. Schemes of rolling
a-plain;
b-transverse;
c-d-skew

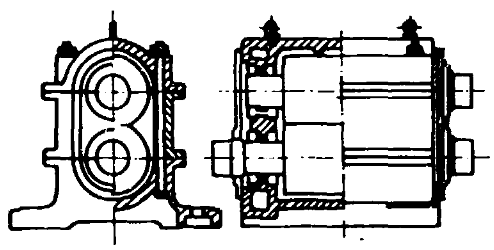

Fig.XII.2. Roller cage

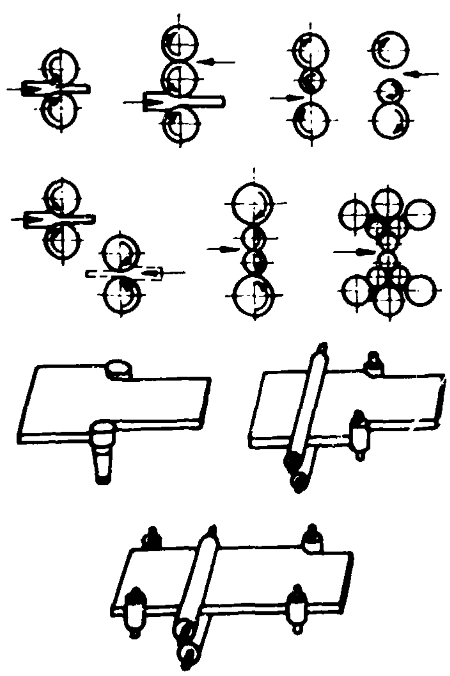

Fig.XII.3. Schemes of rolling

These elements are exposed to the effect of high surface pressure, and therefore they require a great hardness and high abrasion resistance. Metallurgical rolls are made of chromium cast iron, low-alloy and medium-alloy cast steel, the so called, "composite rolls" or bi-metallic cast iron /external working layer/ and grey cast iron or carbon cast steel /core and neck/. The rolls used in the processing industry are usually cast in grey iron; sometimes their surface layer is subjected to hardening.

XIII	Fixed elements exposed to the pressure of liquids or gases

These elements, such as pressure vessels, hydraulic and pneumatic cylinders, must have a high tensile strength and tightness. They are made of grey cast iron, carbon or low-alloy cast steel; in some special cases of Cu or even Al alloys /reduced weight/.

This type of equipment used in the chemical industry requires cast steel, alloy cast iron, or enamelled grey cast iron.

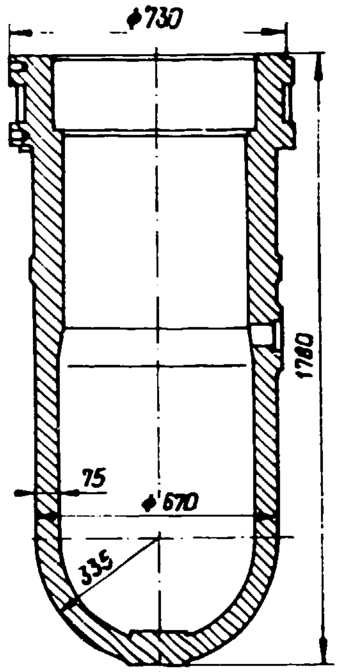

Fig.XIII.1. Cylinder for hydraulic press

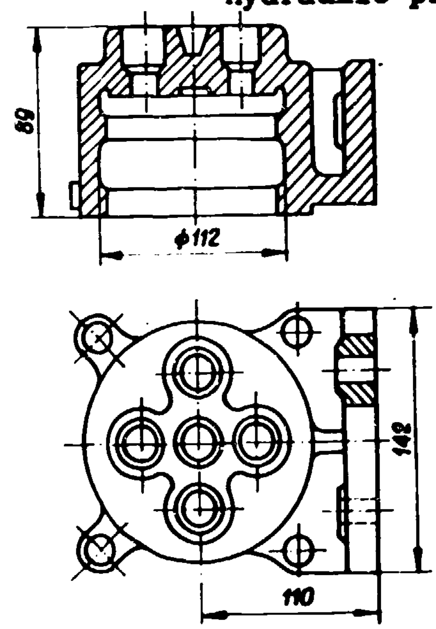

Fig.XIII.2. Valve chest

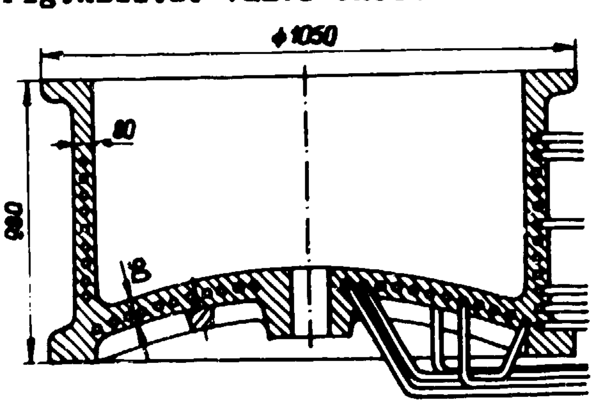

Fig.XIII.3. Frederking's boiler

XIII	Fixed elements exposed to the pressure of liquids or gases

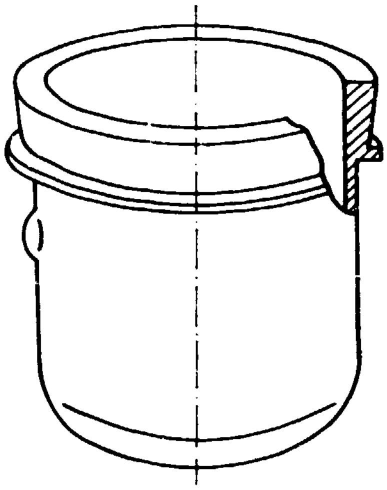

Fig.XIII.4. Boiler

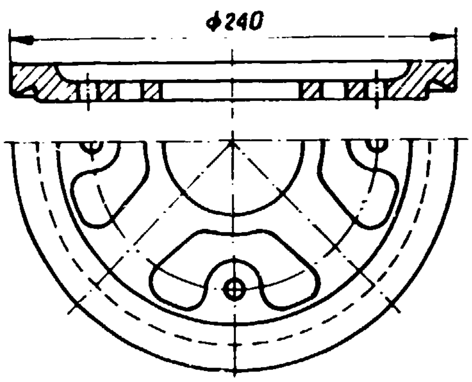

Fig.XIII.5. Condenser cover

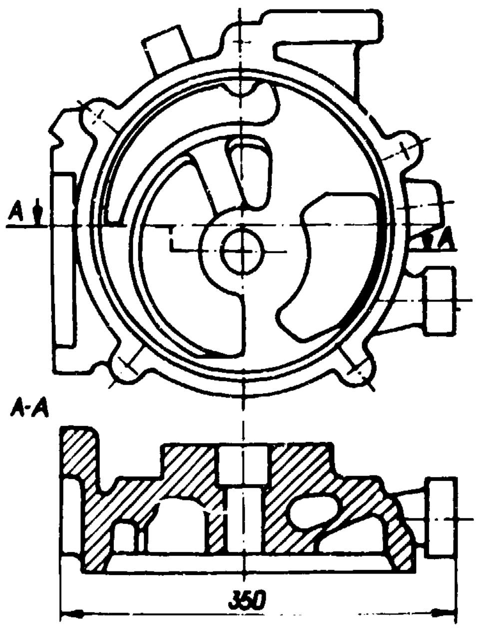

Fig.XIII.6. Head

XIV Elements used for shaping of other metallic elements

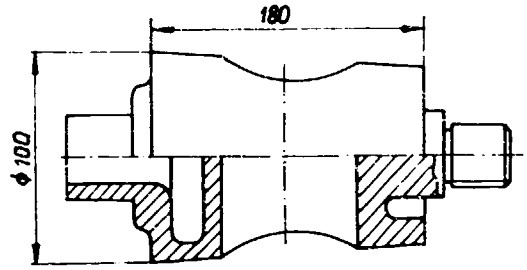

Fig.XIV.1. Section

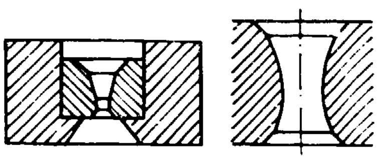

Fig.XIV.2. Drawing die

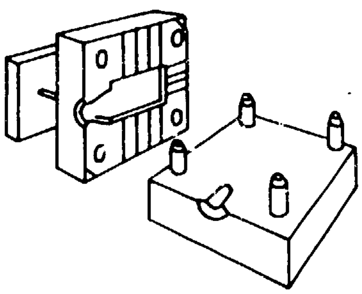

Fig. XIV.3. Casting die

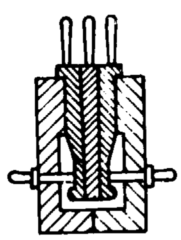

Fig.XIV.4. Chill

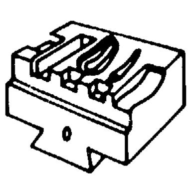

Fig.XIV.5. Die

These elements such as - drawing dies, dies, swages, permanent moulds chills, casting tools, are made of grey or hardened cast iron and of carbon and low-alloy cast steel - for operation at ambient and slightly elevated temperatures.

For the tools contacting liquid or hot metal /casting moulds/ we use grey cast iron, carbon, and low- or medium-alloy cast steel; these tools, which are additionally exposed to the effect of high pressing forces /pressure die casting dies/, are also made of the tool cast steel designed for the work at elevated temperatures.

Drawbacks exposed to a quick wear and the effect of elevated temperatures are made of the hardened alloy cast iron, tool cast steel or stellites.

For the pressure die casting dies and inserts, coming into contact with the liquid metal, Co, Mo or Cu alloys are applied /Be or Si bronzes/.

Moulds for centrifugal casting are made of the constructional, low-alloy cast steel, grey cast iron or carbon cast steel.

Moulds for plastics /dies/ and for glass are also made of copper with additions of beryllium or chromium.

XV Elements of the electro-technical and welding equipment

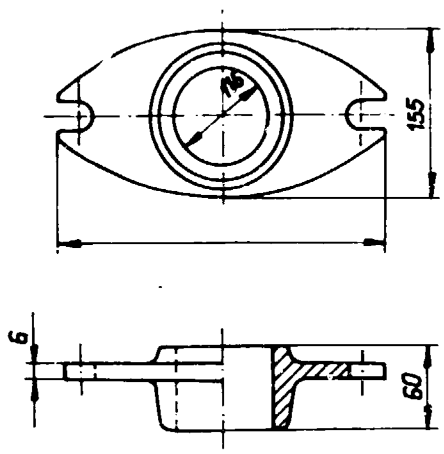

Fig.XV.1. Flange of insulator

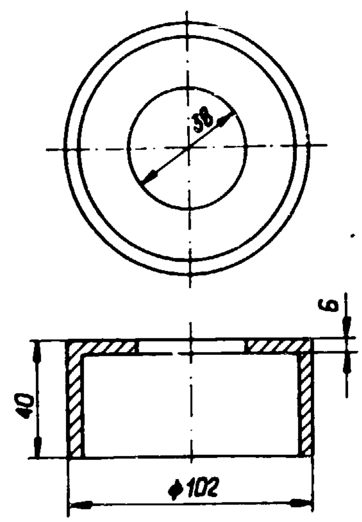

Fig.XV.2. Cap of insulator

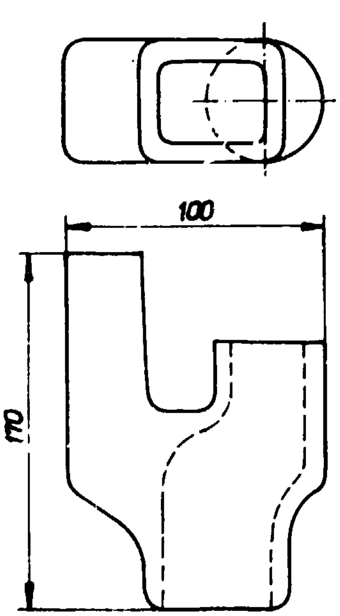

Fig.XV.3. Boxheader

These elements which do not require electrical conduction, such as f.ex. the elements used for fixing the other elements /caps/, are made of malleable cast iron, while the elements, which require appropriate electrical conduction or heat extraction, are made of the extra pure copper, of copper with small additions of Be, and Cr, or of brasses.

The plates of accumulators are cast in Pb or Cd alloys.

XVI	Elements used for the determination of weight or for an additional loading of the equipment

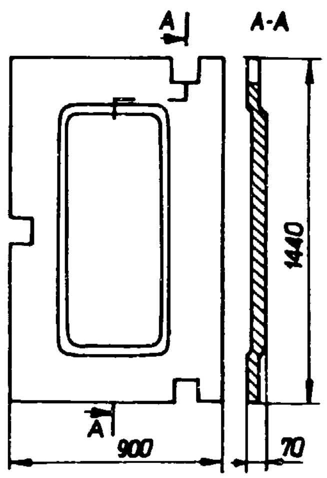

Fig.XVI.1. Plate bob

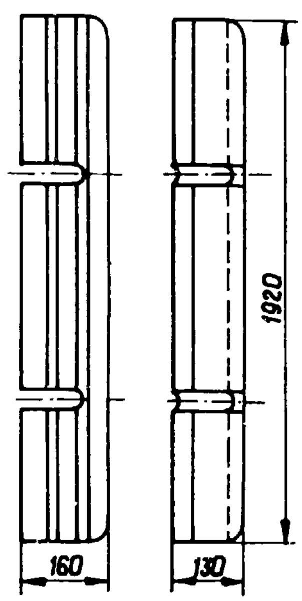

Fig.XVI.2. Bob

These elements, such as f.ex. weights or bobs, require only the accuracy of shape and lack of defects on the surface. They are made of the grey cast iron with flake graphite.

XVII	Elements exposed to severe friction, abrasion and impacts

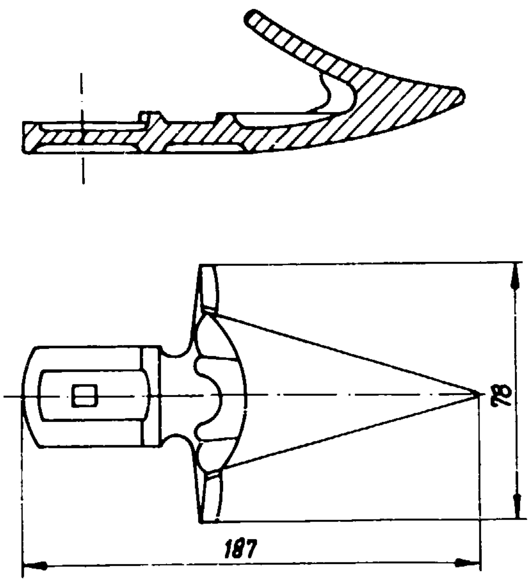

Fig.XVII.1. Mover fingers

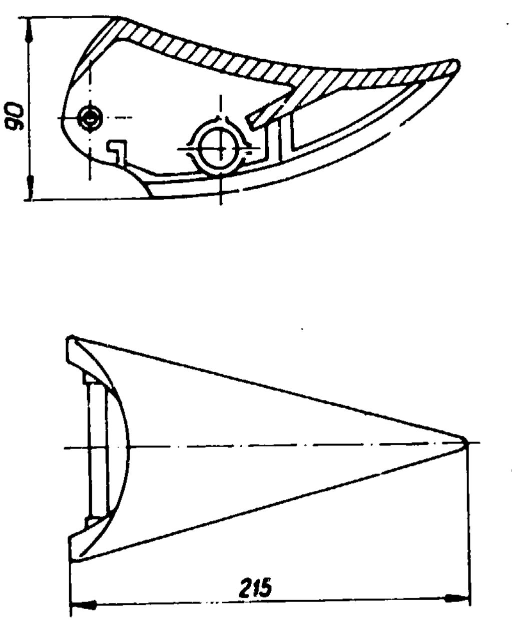

Fig.XVII.2. Divider blade

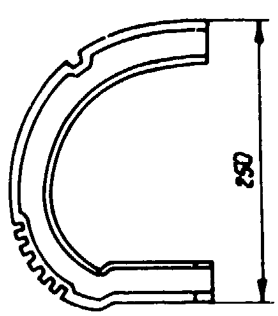

Fig.XVII.3. Comb

These elements, exposed to severe conditions of work during crushing, grinding and mulling of ceramic materials, such as linings of mills, balls and other mulling elements, are made of the abrasion-resistant alloy cast steel /including manganese Hadfield steel/, or of grey, alloy and hardened cast irons.

Similar operating conditions are encountered in the case of some elements included into the agricultural machines, such as divider blades, mover fingers /malleable cast iron, spheroidal graphite cast iron, abrasion-resistant cast steel/ as well as caterpillar member links /high-manganese cast steel/. Hammer faces, drop weights, bodies of buffers and couplers, made of carbon and low-alloy cast steel, are exposed to relatively high impacts only.

XVIII Castings used in household and as ornaments

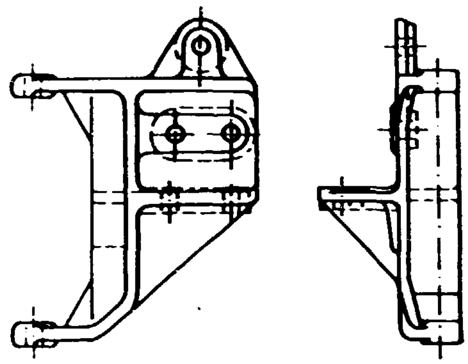

Fig.XVIII.1. Console

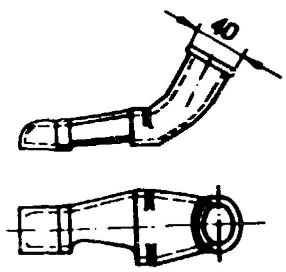

Fig.XVIII.2. Connector

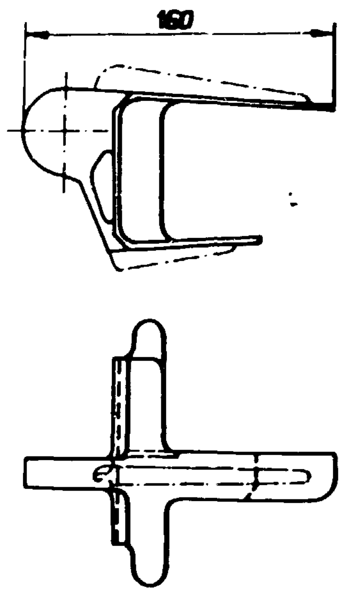

Fig.XVIII.3. Clamping ring

These elements are exposed only to some small impacts and the effect of food or detergents; these are: pots /grey cast iron, Al alloys/, parts of household food mixers, juice squeezing machines, meat grinders, washing machines /Al alloys, stainless cast steel/. Castings made of cast iron and Al alloys are used in sewing machines, vacuum cleaners and refrigerators. Cookers and water heaters require, apart from iron castings /grates, plates/, also Cu alloys /brasses/ for the parts of gas burners.

Household ornaments, ferrules of the household equipment, etc. are made of Cu alloys /brasses/ or Al alloys, ornamented kitchen utensils - of Sn alloys, ornaments and souvenirs - of Bi alloys /low melting point/. Art castings are made of Cu alloys /tin-zinc bronzes/ or cast iron.

Bells are cast in tin-zinc bronzes, silicon bronzes, or even in spheroidal graphite cast iron.

5. Identification of the cast material

Whenever it becomes necessary to replace the worn or damaged element of a machine or equipment, we should determine the way in which it was made, i.e. by means of casting, forging, pressing, welding or pressure welding, etc. The cast parts, especially in the case when they have an unmachined surface, differ from the elements forged, pressed or rolled in a higher surface roughness; only the precision-cast elements have the surface roughness similar as the elements made by means of plastic working. What is also typical of the cast parts are some technological allowances which create bends on the contact surfaces of the perpendicular walls, soft curvatures and rounded contours /Fig.5.1/.

In the case of cast elements /and not only/ the best method to identify a casting alloy consists in the determination of its chemical composition, which is usually obtained by means of the chemical, physical-chemical or physical methods /Table 5.1/.

When it is difficult to carry out in practice an analysis, an approximate evaluation of the alloy /i.e. of the presence of the main elements/ can be made by means of the, so called, drop test, very popular in the case of aluminium alloys. Table 5.2 shows an application of the drop test to the cast aluminium alloys, using /according to the scheme/ the following chemical reagents applied in the form of drops onto the surface of the tested element /cleaned with a torch/:

1 - drop of sodium hydroxide NaOH

2 - after drying, a drop of nitric acid HNO_3,

3 - neutralization with a drop of ammonia NH_4Cl

4 - 1% alcohol solution of dimethylglyoxyne on a wetted paper

5 - grains of sodium bismuthate digested in a sediment

6 - 5% aqueous solution of cadmium sulphate $CdSO_4$ /+ 3% aqueous solution of NaCl and 5% solution of HCl/

7 - dissolving of filings in an aqueous solution of HCl and HNO_3 /in a ratio of 1 : 1 : 1/.

There are also other simplified drop tests for Al and Mg alloys and for the tin bronzes, the latter ones being less popular. The drop tests are not only approximate, but most unfortunately also selective, i.e. they are applicable only to some groups of the non-ferrous metals alloys.

Certain approximate identification of the group of alloys is possible basing on the determination of the colour of a casting, its weight and hardness /Table 5.3/.

In the group of, f.ex., copper alloys there is a great variety of colours, from the red copper to the light-yellow brasses, with greyish-red alloys of copper and lead /lead bronzes of an elevated content of lead/, grey-red-yellow, tin-lead bronzes, steely-grey-yellow, aluminium bronzes and similar, although more greyish silicon bronzes, Copper has a colour very similar to the alloyed copper and to these bronzes in which the alloy addition is relatively low, such as f.ex. beryllium or chromium bronzes.

Hardness of alloys depends not only on the properties of the material, but also on the way in which it is measured. This quantity can neither be defined nor measured in an absolute way, and to some extent it is of a conventional nature. Hardness is characterized by a resistance of the surface of the tested element in respect to the pressed down ball, cone or quadruple pyramid.

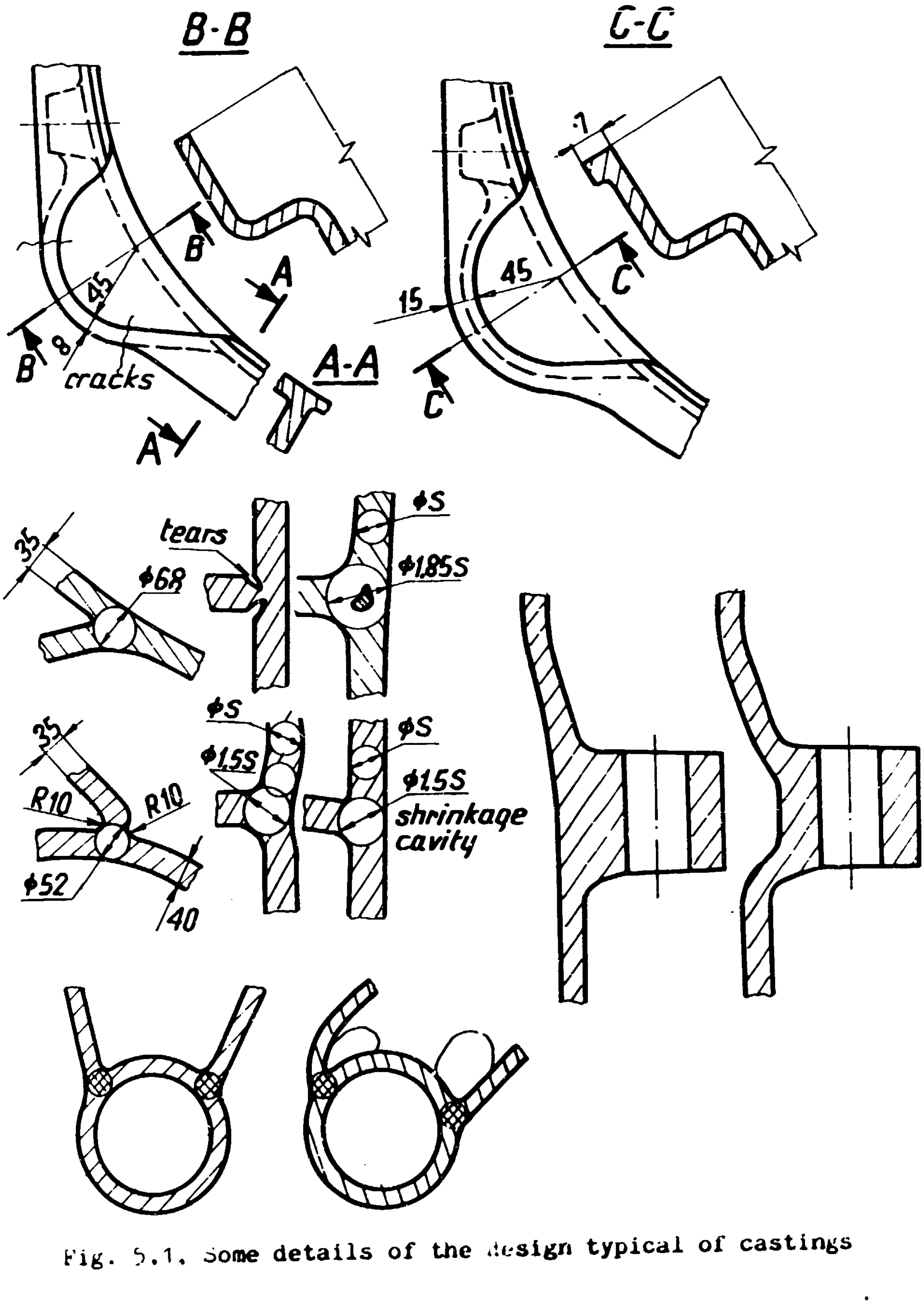

Fig. 5.1. Some details of the design typical of castings

Table 5.1. Methods for determining the chemical composition of metals and their alloys

Methods

1. Qualitative

1.1. Classical /chemical/

1.2. Spectroscopy

2. Quantitative

2.1. Classical /chemical/

2.1.1. Weighing

2.1.2. Titration: /volumetric/, alkacymetric, redoximetric, precipitation, complexometric

2.2. Physical-chemical /instrumental/, such as:

2.2.1. Electrolytic

2.2.2. Potentiometric

2.2.3. Polarographic

2.2.4. Amperometric-titration

2.2.5. Conductometric

2.2.6. Photometric

2.2.7. Spectrophotometric

2.2.8. Fluoroscopic-fluorescent

2.3. Physical

2.3.1. Spectrographic

2.3.2. Spectrometric

3. Semi-quantitative

3.1. Steeloscopy

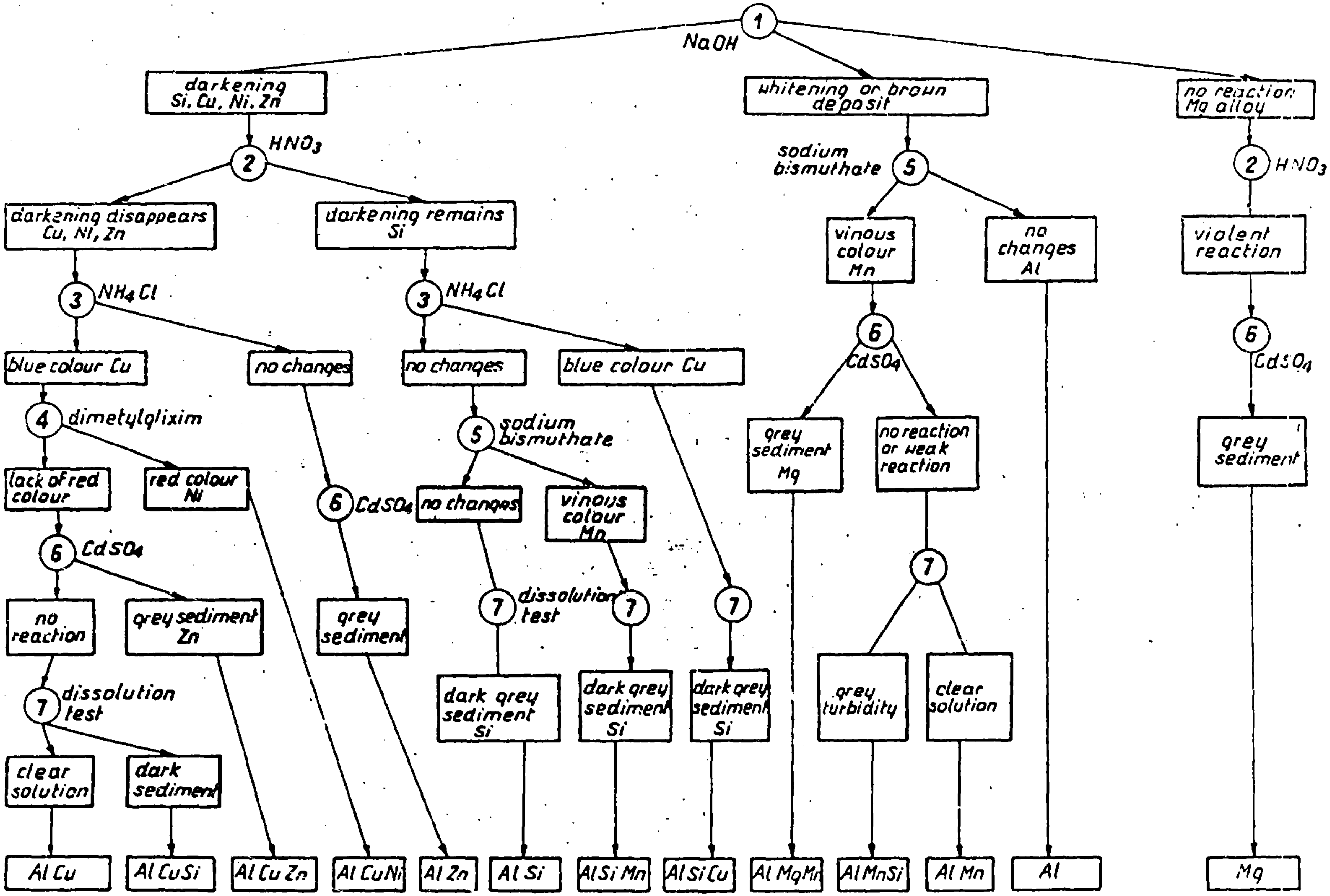

Table 5.2 Drop test as applied to casting Aluminium alloys

Table 5.3. Approximate determination of casting alloy type

Cast material	Colour of casting surface	Specific weight x/ g/cm^3	Hardness xx/ HB
grey cast iron with			
- flake graphite	grey	7.2 - 7.35	200-300
- spheroidal graphite	silver-grey	7.1 - 7.3	140-300
white cast iron	grey		
malleable cast iron			
- whiteheart	silvery	6,8-7,8	220-230
- blackheart	dark grey		150-160
- pearlitic	grey		150-310
cast steel	silvery		130-330
superalloys	blue silvery	8,8-9,0	170-210
Cu alloys	red to light yellow	7,5-8,9	25-200
Al alloys	silvery grey	2,6-2,95	50-115
Mg alloys	grey	1,8-1,85	40-65
Zn alloys	silvery	4,7-6,8	65-100
Pb alloys	silvery grey	8,5-10,7	15-35
Si alloys	grey	7,6-8,5	27-32
Ni alloys	bluish silvery	7,8-8,8	100-400

x/ is used for an approximate determination in the case of similar colours and hardness value,

xx/ may be determined also with Poldi hardness tester.

Casting alloys are tested by means of a Brinell method which consists in pressing down a hard, calibrated, steel ball into a flat, sufficiently smoothed surface of the examined object or specimen, applying a thrust /force/ perpendicular to this surface and measuring, after the thrust has been relased, the diameter of the permanent ball indentation left on the surface of the examined object. The Brinell hardness test is applicable to the metals and their alloys having a hardness of up to 500HB. Exceptionally, using special balls, we can measure the hardness of up to HB = 600, but usually it is accepted that with HB $>$ 400 other methods of measurement should be used, f.ex. Rockwell or Vickers hardness tests.

Poldi hardness test /Fig. 5.2/ was based on the Brinell test, and it consists in pressing down a steel ball into the material tested and at the same time into a reference plate of the determined hardness. Measuring with a graduated magnifying glass the diameter of both indentations, we calculate hardness of the examined object.

The drawback of Poldi test is its relatively low accuracy, while the advantage is a possibility of measuring hardness on large castings and in the spots usually inaccesible to the Brinell hardness tester.

There are also other methods of measuring the hardness, incomparable or hardly comparable with the main ones /Brinell, Vickers/, which may sometimes be used for an identification of the material. This is f.ex. the measurement of hardness with the shore scleroscope /utilizing the elastic properties of the examined material and of the ball, the measurement of the height of the ram spring back way/, or the measurement carried out with the Herbert pendulum /HB = 13,5 H_{Hero}/, but its reliability and scope are not very sure.

The hardness test used for the purpose of identification does not vary very much for particular groups of alloys, and it is additionally complicated by a possible heat treatment, applied quite often in the case of aluminium alloys. Therefore the hardness test can be useful only when applied together with other tests, like f.ex. the drop test and an estimation of the casting colour.

When the cast material is identified, and especially when the state of the casting is to be determined / as cast after heat treatment/, it is very useful to determine the microstructure of an alloy, i.e. to examine under a metallographic microscope the section from a part of the casting or the test piece, polished and possibly also etched with an appropriate chemical reagent. For the purpose of identification it is sufficient to provide an enlargement of 100 and 500 times. This identification also enables a determination of the structure, and hence a differenciation between the element that was cast, forged, pressed or rolled.

6. Substitute alloys

Quite often in the production of castings the economical aspects are also taken into consideration, namely the advisability of using some materials or particularly expensive alloying elements, like f.ex. Mo, Co, W, Ni, Sn or Cu, is discussed. This creates some specific tendencies in the price levels of castings, different in different castings. Table 6.1 gives an exemplary estimation of the cost of castings made in some selected groups of alloys.

In the general concept of choosing materials and alloying elements less deficient, Mo is replaced by Si and Mn in the alloyed steel, Sn by Si or Al in bronzes /silicon and aluminium bronzes instead of tin bronzes/, Cu by Zn /brasses of a low Cu content/, Cu alloys by grey cast iron, cast steel by s.g. cast iron, etc.

From the point of view of the spare parts the use of substitute materials has no economic effects, but it may prove necessary when it comes to making the production more easy or even possible at all. A set of information on the selection of substitute materials is given in Part 3 of this paper where the variant materials have been ennumerated.

Table 5.1. Cost of some selected castings made of ferrous and non-ferrous alloys in terms of the direct and synthetic indices basing on the price relations in Poland at the end of seventies

Casting alloys	Cost of casting x/			Synthetic index xxx/ $A = \frac{zł}{dm^3}\ \frac{1}{Rm/MPa}$	
	zł/kg	relative index xx/ zł/dm³	relative index zł/dm³	scatter of values	average
1. Carbon cast steel	9,00 - 69,50	0,6 - 4,6	65 - 515	0,18 - 1,29	0,73
2. Low- and medium alloyed cast steel	9,50 - 97,00	0,6 - 6,4	70 - 740	0,063- 1,64	0,851
3. High-alloyed, stainless, heat-resisting, tool cast steel	46,50 -344,00	3,1 -22,8	360 -2700	0,23 - 6,43	3,33
4. Grey cast iron with flake graphite	15,10 - 40,20	1 - 2,7	110 - 290	0,28 - 2,9	1,59
5. Spheroidal graphite cast iron	27,20 - 53,00	1,8 - 3,8	200 - 430	0,22 - 1,13	0,68
6. Malleable cast iron	32,50 - 69,00	2,2 - 4,6	240 - 500	0,34 - 1,67	1,00
7. Copper alloys-bronzes	59,30 -204,00	3,9 -13,5	510 -1750	0,63 -29,17	14,93
8. Copper alloys-brasses	49,20 -144,10	3,3 - 9,5	370 -1080	0,74 - 5,4	3,07
9. Zinc alloys	41,20 - 93,10	2,7 - 6,2	280 - 630	0,93 - 4,2	2,57
10. Alluminium alloys	29,70 -147,20	2,0 - 9,7	85 - 420	0,26 - 2,8	1,53

x/ The higher the price, the lower the casting weight. In the case of non-ferrous metals alloys /Cu, Al, Zn/ the cost of material amounts to about 75% of the cost of production for sand castings, and to about 120% for die castings. In the case of die castings the cost of castings also depends on the size of the lot.

xx/ The relative index of the cost of a casting has been obtained assuming that the lowest cost of 1 kg of a casting made in grey cast iron with flake graphite /item 4/ equals a unity /15,10 = 1,0/. With this assumption the relative index was calculated with an accuracy of one tenth.

xxx/ A serious scatter occurs after calculation of the extreme values; the average value is more representative, although it is an arithmetic mean of the extreme values. The lower is the value of index A, the lower is the cost of obtaining 1 dm³ and 1 MPa of the strength in the manufactured casting.

7. Application of casting processes in the manufacture of spare parts for machines and equipment

7.1. Choice of the manufacturing process

Foundry practice has at its disposal numerous manufacturing methods, and the choice of one of them depends on various factors. A characteristic of these methods is given in Table 7.1. Among them, production of spare parts covers only a small fragment of the table due to the following reasons:

- small demand,
- simplified procedure of making pattern equipment,
- limited possibilities of the spare parts-making foundries.

Most often, the spare parts will be made according to the procedure described in Column 1 of the above mentioned Table 7.1. The other methods will be applied rather rarely: Column 2 /hand strickle moulding/, Column 6 /moulding with expendable patterns/ and Column 5 /moulding with investment patterns/.

7.2. Making a foundry pattern

A foundry pattern, or strictly speaking a set of patterns, consists of an equipment which enables conferring to the moulding sand packed in a moulding box the required shape of the mould cavity as well as making the cores which reproduce the interior of a casting. This also includes parts of the equipment which ensures correct casting of the elements under given technological conditions. The elements included into a pattern equipment set are illustrated on the drawings given in Chapter 7.3.

In the case of making a spare part of the complicated shape, it is important to think whether it would be possible to use the

Table 7.1.

Characteristics of the methods of manufacturing castings

Characteristics of casting process	In non-permanent /single-use/ moulds						In permanent moulds			
	With permanent patterns				With expendable patterns		Without patterns			
	Hand moulding with pattern	Hand moulding with a strickle	Machine moulding	Moulding in boxes	Moulding with investment patterns	Moulding with expendable patterns	Permanent mould casting	Pressure die casting	Casting in spinning moulds	Continuous casting
1	2	3	4	5	6		8	9	10	11
Pattern equipment	Patterns and core boxes of different quality made of wood	Strickles turned over or stripped possibly with patterns	Metal plates and core boxes, possibly of plastics	Metallic heated patterns and core boxes	Casting of wax patterns in moulds made of metals and plastics	Simple-use patterns made of foamed plastic /polystyrene				
Moulding material	Natural or synthetic sands, clay, chemo- or thermosetting binders	Natural sands, cement sands or bricklayed moulds	As in column 2	Resin-coated silica sands with phenolic binders	Ceramic sands with binders /ethyl silicate, water glass, etc./	Various materials	Cast iron or cast steel dies	Carbon steel dies for Zn, Pb and Sn alloys; alloyed steel dies for Cu and light metals alloys	Cast iron or cast steel water-cooled dies	Cast iron, steel or copper, water-cooled dies
Mould making process	Hand packing of sand or with pneumatic rammers /possibly also on slingers	Hand packing of sand	Machine moulding and core making. Mechanized transport of materials and moulds	Hardening of sand applied onto a hot pattern plate or core box	Joining of wax patterns with downgate. Application of ceramic coating onto patterns. Baking of shells	Moulding of unsplit patterns. Hand or machine packing of sand	Dies made by means of casting or machining	Dies machined and then assembled	Dies constructed as in column 8. Casting on machines with vertical or horizontal axis of rotation	Crystallizer /continuous passage die/ with vertical or horizontal outlet
Casting process	From hand-operated or crane ladles	From crane ladles	From crane ladles or special equipment	As in column 4	Low-pressure casting, vacuum casting, centrifugal casting or from ladle	As in columns 2 or 3; different gating system	Casting with hand shank or ladle from furnace of constant temperature	Forcing of liquid or pastelike metal into a die	Metal supplied by a tapping spout and forced into die by a centrifugal force	Continuous casting with machine lowered core or drawing of sections
Type of alloy cast	All alloys	Cast iron, steel, Cu alloy	All alloys	All alloys, usually cast iron and steel	All alloys, usually alloy cast steel and hard alloys	All alloys	Light metals alloys, brasses, cast iron, rarely cast steel	Al, Mg, Zn, Cu, Sn and Pb alloys	Cast iron, cast steel Al and Cu alloys	Cast iron, cast steel, Cu alloys
Weight of unit casting	From several tens grams up to 200 t, depending on transport means	From several tens kilograms up 200 t	Up to 5 t, with slinger up to several dozen tons	0,2-150 kg	Up to 1 kg, exceptionally up to 30 kg	Very heavy castings	From several tens grams up to about 100 kg /exceptionally heavier/	In alloys up to 20 kg Al alloys up to 30 kg Cu alloys up to 5 kg /depending on type of machine	Up to 5 t	Up to 3 t

damaged part as a pattern or a core box, even if it means additional adaptation works. In such a case, advantageous and bringing savings in both the time and materials, it is again important to ensure an enlargement of the pattern dimensions in comparison with the ready spare part to account for the casting contraction and to introduce the machining and technological allowances. The, so called, technological allowances are necessary to ensure appropriate taper of patterns and core boxes, which is required in the process of sand packing and the subsequent withdrawal of a pattern from the mould. The technological allowances enable the obtention of a compact internal structure in the cast walls. They include: feeder heads, passages between walls, fillets in the walls joints, etc.

The values of the casting contraction for different casting materials are given in Table 7.2.

The required increase in the pattern dimensions in relation to the original cast part can be obtained attaching to this part appropriate elements made of wood, steel sheet or plastics. We can also apply very primitive but none the less quite effective means to enlarge the mould cavity in relation to the applied moulding pattern. This procedure consists in "tapping" strongly the pattern after packing the sand in a foundry mould, which increases the dimensions in these directions in which the "tapped" pattern is moving.

If it is impossible to use the damaged part as a pattern, we can use hardened polyvinyl chloride to make a pattern. Then it is possible to select the most advantageous forms of this material which is usually manufactured as plates, rods, or pipes. The advantages of applying this technology of pattern - making

Table 7.2.

Casting contraction after DIN 1511 /in %/

Material	Mean values	Scatter
Cast iron with graphite		
flake	1,0	0,5 - 1,3
spheroidal, as-cast	1,2	0,8 - 2,0
spheroidal, annealed	0,5	0,0 - 0,8
Cast steel	2,0	1,5 - 2,5
Manganese cast steel	2,3	2,3 - 2,8
Blackheart malleable cast iron	0,5	0,0 - 1,5
Whiteheart malleable cast iron	1,6	1,0 - 2,0
Aluminium alloys	1,2	0,8 - 1,5
Magnesium alloys	1,2	1,0 - 1,5
Copper alloys /electrolyte/	1,9	1,5 - 2,1
Bronzes	1,5	0,8 - 2,0
Brasses	1,2	0,8 - 1,8
Zinc alloys	1,3	1,1 - 1,5
Lead-tin alloys	0,5	0,4 - 0,6

are as follows: it is easy to join together parts made of the hardened polyvinyl chloride and to machine them, while the pattern as such has a very long life.

Further, we should also take into consideration the possibility of casting patterns in epoxy resins, of making laminated pattern equipment, and of using for this purpose foamed polystyrene.

7.3. Examples of making cast spare parts

7.3.1. Flywheel

A flywheel weighing about 900 kg is shown in Fig.7.1. Due to a considerable degree of damages in this casting, its weight which makes difficult using the casting as a pattern, and a very laborious assembly of the elements providing the machining and technological allowances, it was decided to make a pattern in the foamed polystyrene. In this way considerable savings were obtained in the time of making the pattern and moulding, since it was possible to eliminate the operation of parting the mould in the "windows" of the casting, indispensable in view of the required wall draft. The construction of a foundry mould is shown in Fig.7.2.

7.3.2. Control cage for a centrifugal shot blasting machine

A control cage worn due to the effect of shot is shown in Fig.7.3, while the ready spare part cast in alloy iron is shown in Fig. 7.4. Since it was possible to make the pattern on a lathe, it was decided to use wood for the pattern and core box. The values of the machining and technological allowances are given in Fig. 7.5. The next drawing /7.6/ shows the construction of a foundry mould.

7.3.3. Impeller for a centrifugal shot blasting machine

This casting was also made of alloy cast iron. It is mated with the control cage and is exposed to a quick wear due to the action of shot /Fig. 7.7/. The applied machining and technological allowances are shown in Fig.7.8, while the ready casting is shown in Fig.7.9.

Fig.7.10 shows the foundry mould with a central core, situated in its top part. Due to easy machining, the pattern was made in wood. The core box was made using a fragment of the worn casting; this is shown in Fig.7.11. Losses in the part of the casting used to reproduce the cavities in the core were repaired with resin or plaster.

7.3.4. Pump impeller

The ready casting of the pump impeller is shown in Fig.7.12, while the machining and technological allowances as well as the gating system are shown in Fig.7.13.

A considerable degree of the shape intricacy in this casting makes it unprofitable to prepare a new pattern in special wood or metals alloy. Therefore, it was decided to repair the losses in the impeller blades with resin and plaster, while the machining and technological allowances were provided applying a layer of plastic on the marked surfaces of the worn casting. It is quite easy to machine this material, and therefore the pattern can be prepared for moulding very quickly /Fig.7.14/.

7.3.5. Blade for a centrifugal shot blasting machine

The blade for a centrifugal shot blasting machine shown in Fig.7.15 is an example of the use of the original part as a pattern after the necessary amendments which result from the presence of the curvature of a large radius, visible on the end view of the casting. In this case the casting contraction is compensated enlarging the mould cavity by "tapping" of the pattern. The casting has no machining allowances, since the material used is very hard and hence difficult in machining, while the dimensional accuracy obtained is sufficient. The construction of a mould is shown in Fig.7.16.

7.3.6. Lever

The lever cast in an Al alloy is shown in Fig.7.17. In the manufacture of a new casting the worn part was used, but before it was repaired and the machining and technological allowances were added applying segments of steel sheet, plywood or card board. Similarly as in the previous case, the casting contraction was compensated enlarging the mould cavity by means of "tapping" the pattern. The lever is constructed in such a way that its arms are located in different planes. Due to this it is necessary to place a small core and to part down fragments of the pattern /Fig.7.19/.

7.3.7. Excavator tooth

The method of making the tooth for an excavator shown in Fig.7.20 depends on the required number of these spare parts. It is quite possible to use the casting as a pattern, and the only amendment necessary is to provide two core prints to locate the main /central/ core and to make a core which reproduces the hole through which the tooth is screwed to the excavator /Fig.7.22/.

It is impossible to make this hole by means of machining since the material used for the tooth /high-manganese cast steel/ is unmachinable. The method of making a core box for the central core shown in Fig.7.21 requires cutting tne worn cast tootn with a gas torch, and next applying a layer of the material on its surface. This method is however very troublesome, and therefore whenever it is possible to make the core box of a casting material, a conventional method is much simpler. This is also recommended if a greater number of these castings is demanded.

7.3.8. Piston

Making pistons under simple technological conditions is one of the most difficult processes among those described so far. Figure 7.23 shows the piston made of an aluminium alloy; its internal part is reproduced by an intricate core. If the worn piston is to be used for the manufacture of a core box, this requires parting of the piston into three parts, following the procedure illustrated in Fig.7.25. As it can be seen in this drawing small fragments of the walls are left uncut, and later on when broken enable putting the piston together preserving its original dimensions /Fig.7.26/. The core box for making the central core consists of the three parts visible in Fig. 7.26.

The outer part of the piston is reproduced by a machined die made of cast iron or steel. An assembly of the complete mould is shown in Fig.7.28.

In a similar way it is possible to make the cast iron piston. In such a case, however, it is recommended to change only the way in which the metal is fed to a mould. It is advantageous to place the downgate in the axis of the central core using internal ribs between the bottom of the piston and its walls as a runner feeding the cast iron. The piston made of cast iron can also be manufactured using a sand core instead of the die reproducing the external walls.

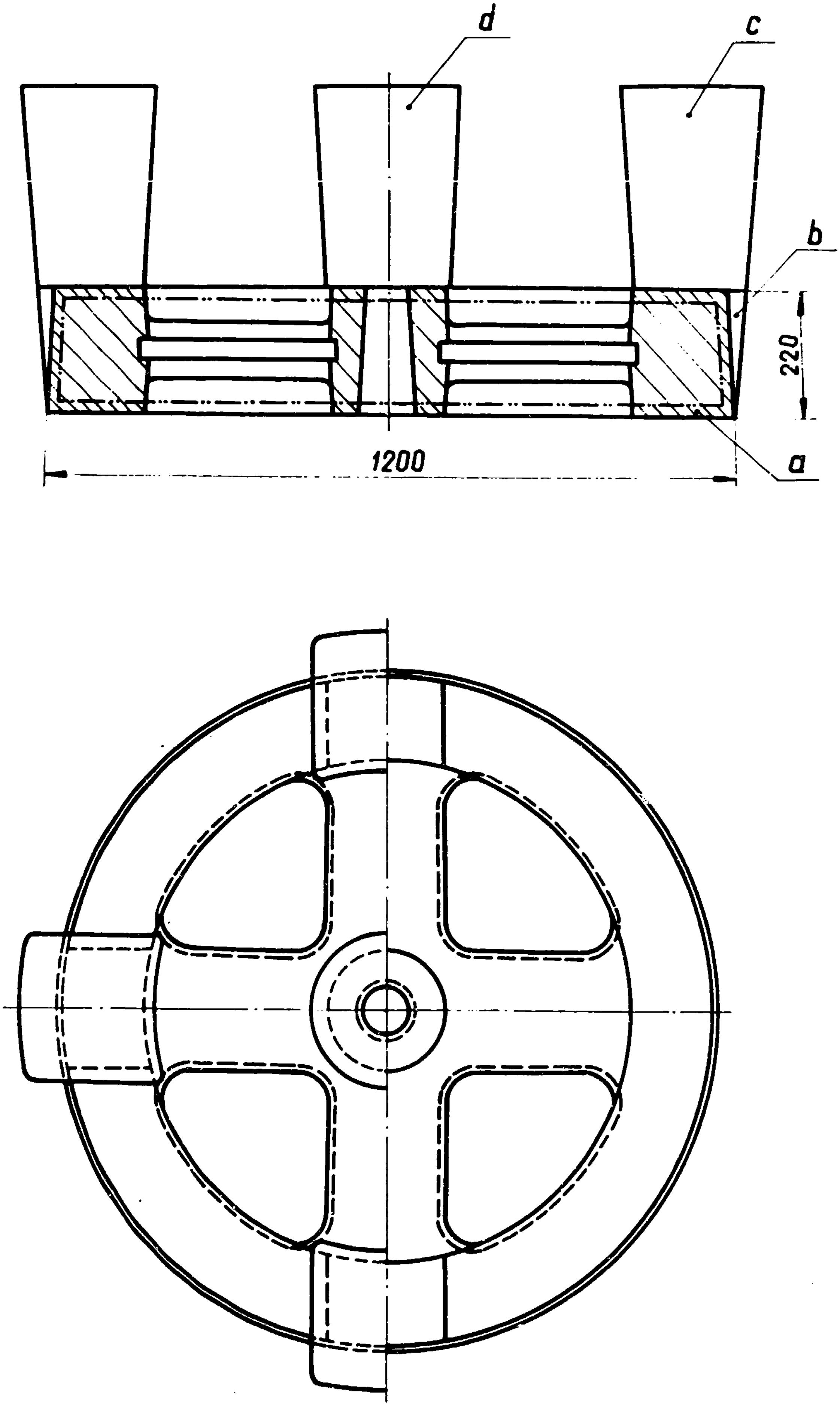

Fig. 7.1. Flywheel cast in grey iron with flake graphite. Drawing of casting with machining allowances /a/, technological allowances /b/, feeder heads /c/ and downgate /d/

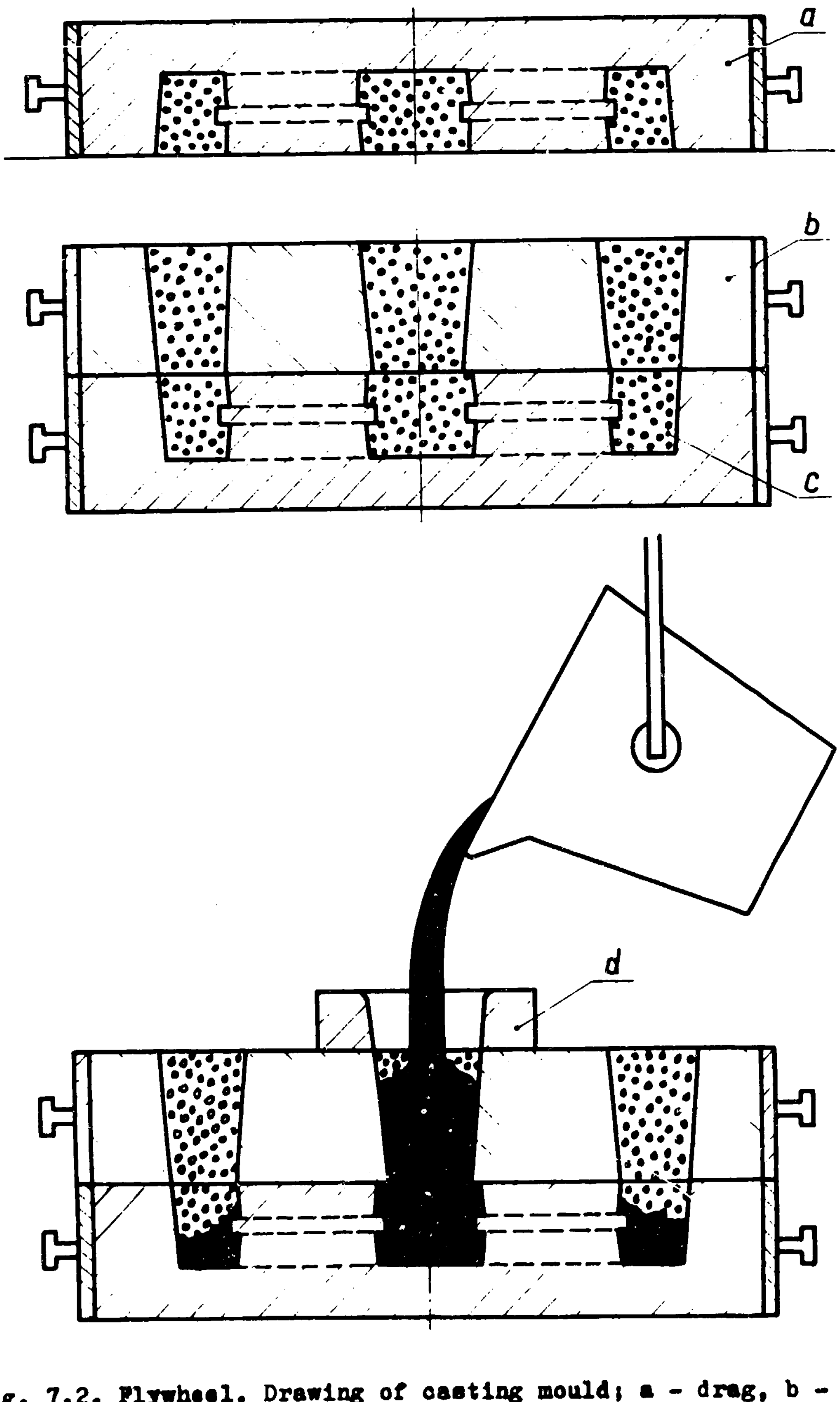

Fig. 7.2. Flywheel. Drawing of casting mould; a - drag, b - cope, c - foamed polystyrene pattern, d - pouring with metal of the assembled mould

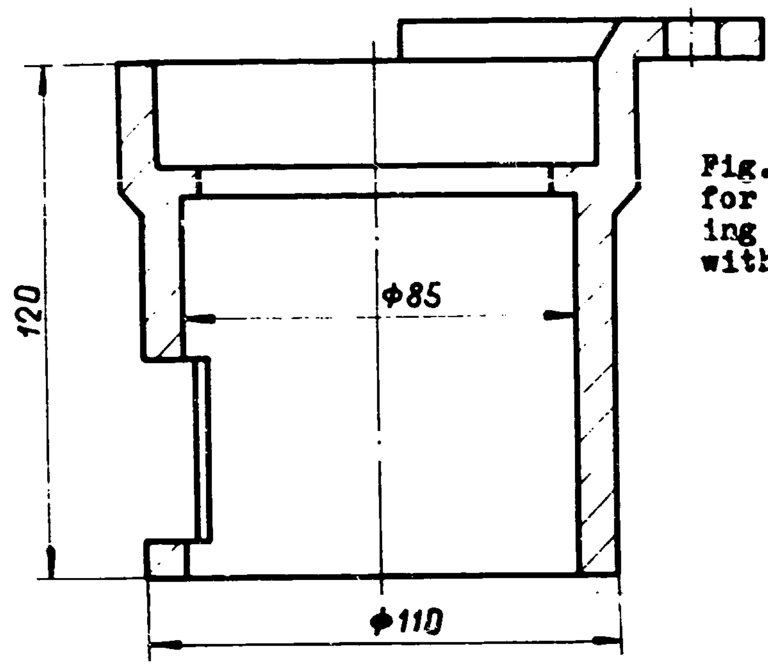

Fig. 7.4. Control cage for centrifugal shot blasting machine cast in iron with an addition of chromium

Fig. 7.3. Control cage for centrifugal shot blast machine. Note traces of wear on the internal and external surfaces and on the shot outlet hole

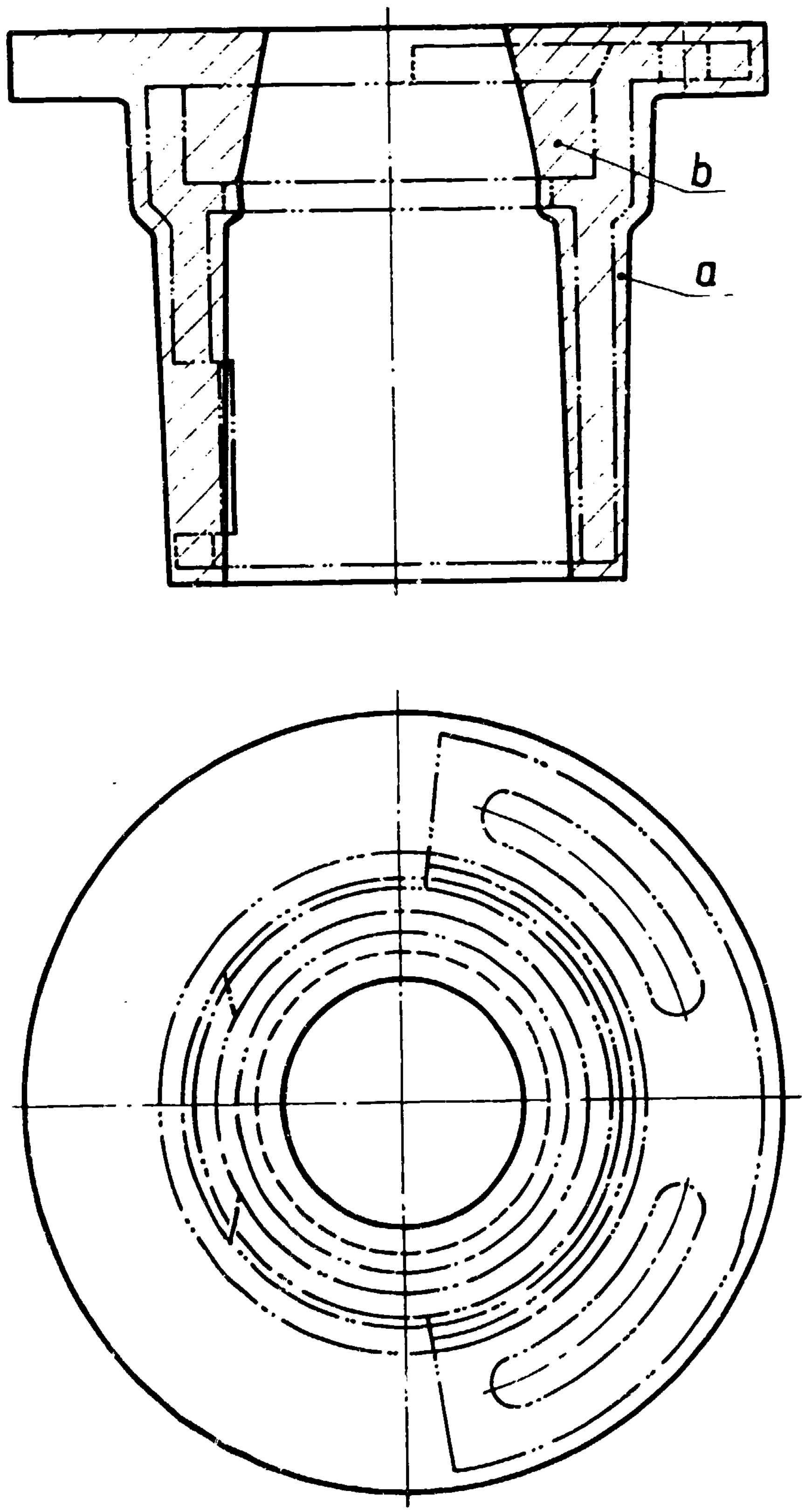

Fig. 7.5. Control cage for centrifugal shot blasting machine. Drawing of casting with machining allowances /a/ and technological allowances /b/

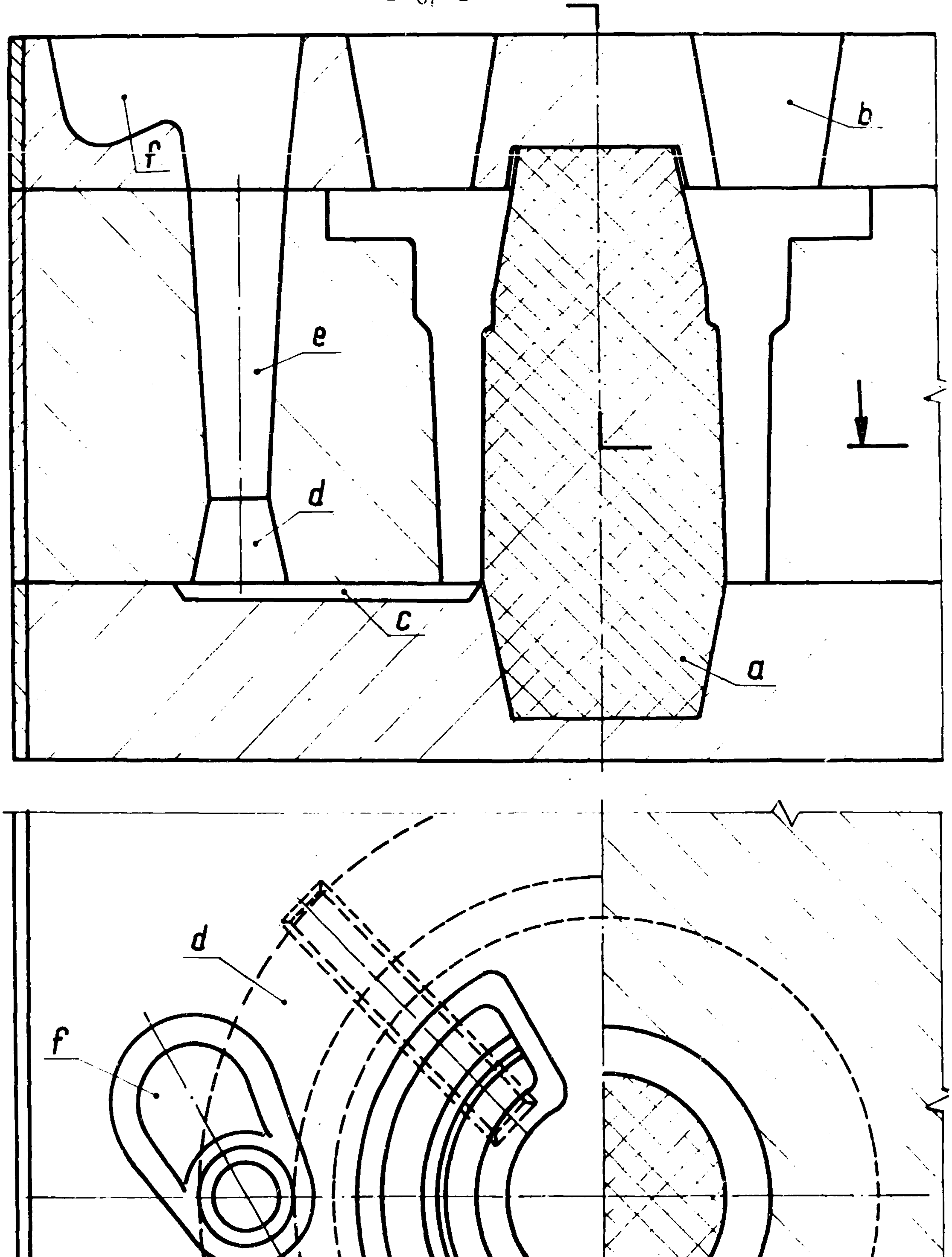

Fig. 7.6. Control cage for centrifugal shot blasting machine. Drawing of casting mould; a - central core, b - feeder head, c - gate runner, d - runner, e - downgate, f - pouring basin

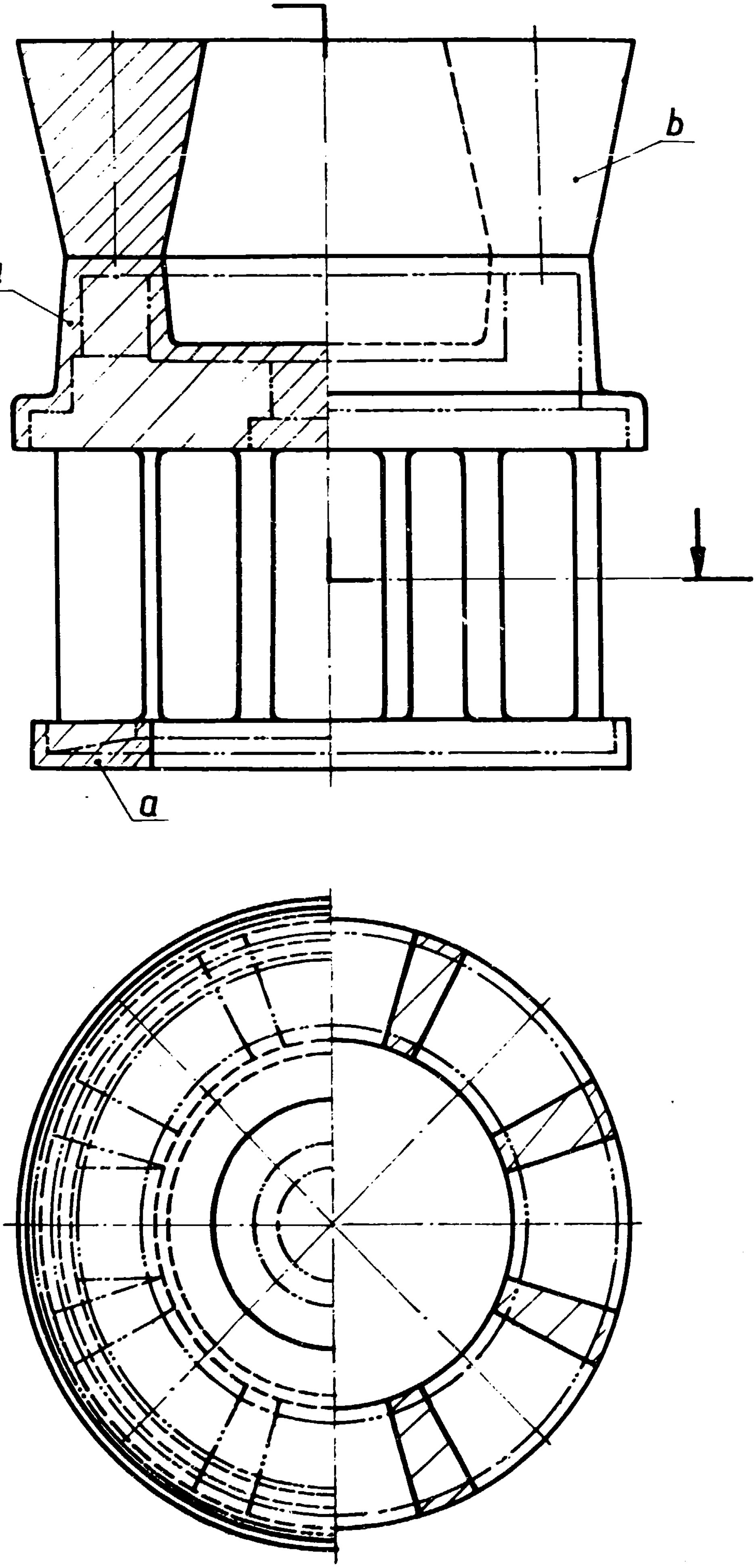

Fig. 7.8. Impeller of centrifugal shot blasting machine. Drawing of casting with mechanical allowances /a/ and feeder heads /b/

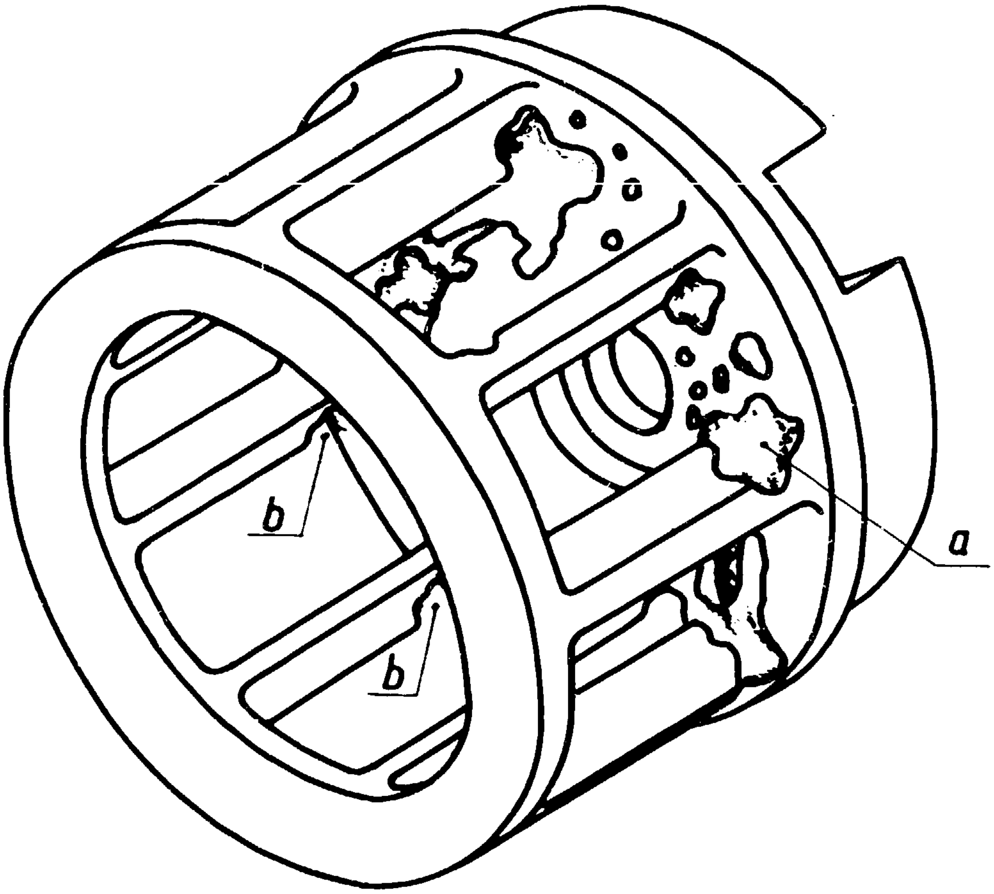

Fig. 7.7. Impeller of centrifugal shot blasting machine. Note traces of wear on impeller passage /a/ and impeller eyes /b/

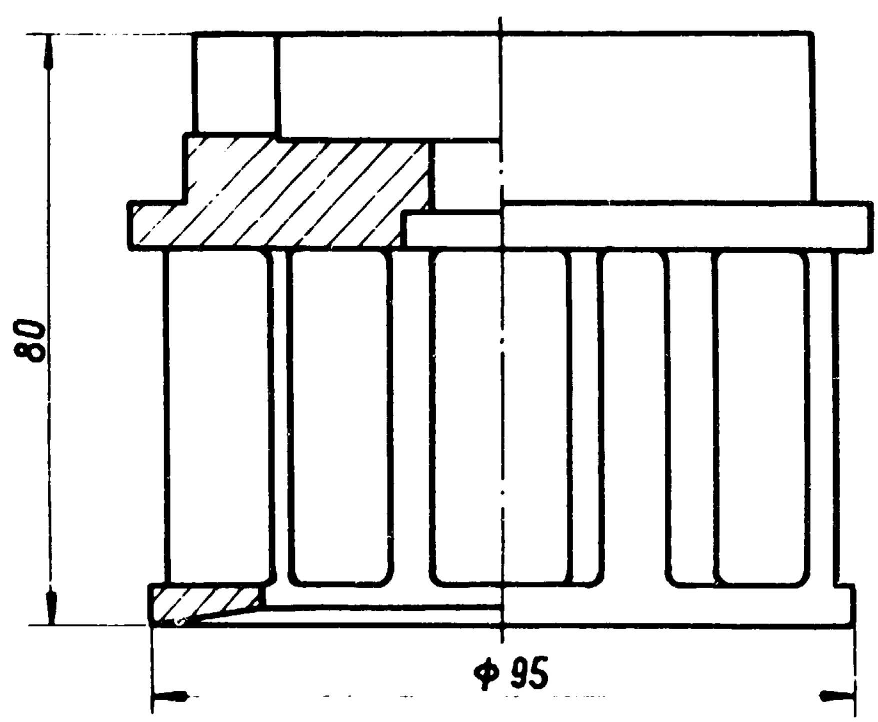

Fig. 7.9. Impeller of centrifugal shot blasting machine cast in iron with an addition of chromium

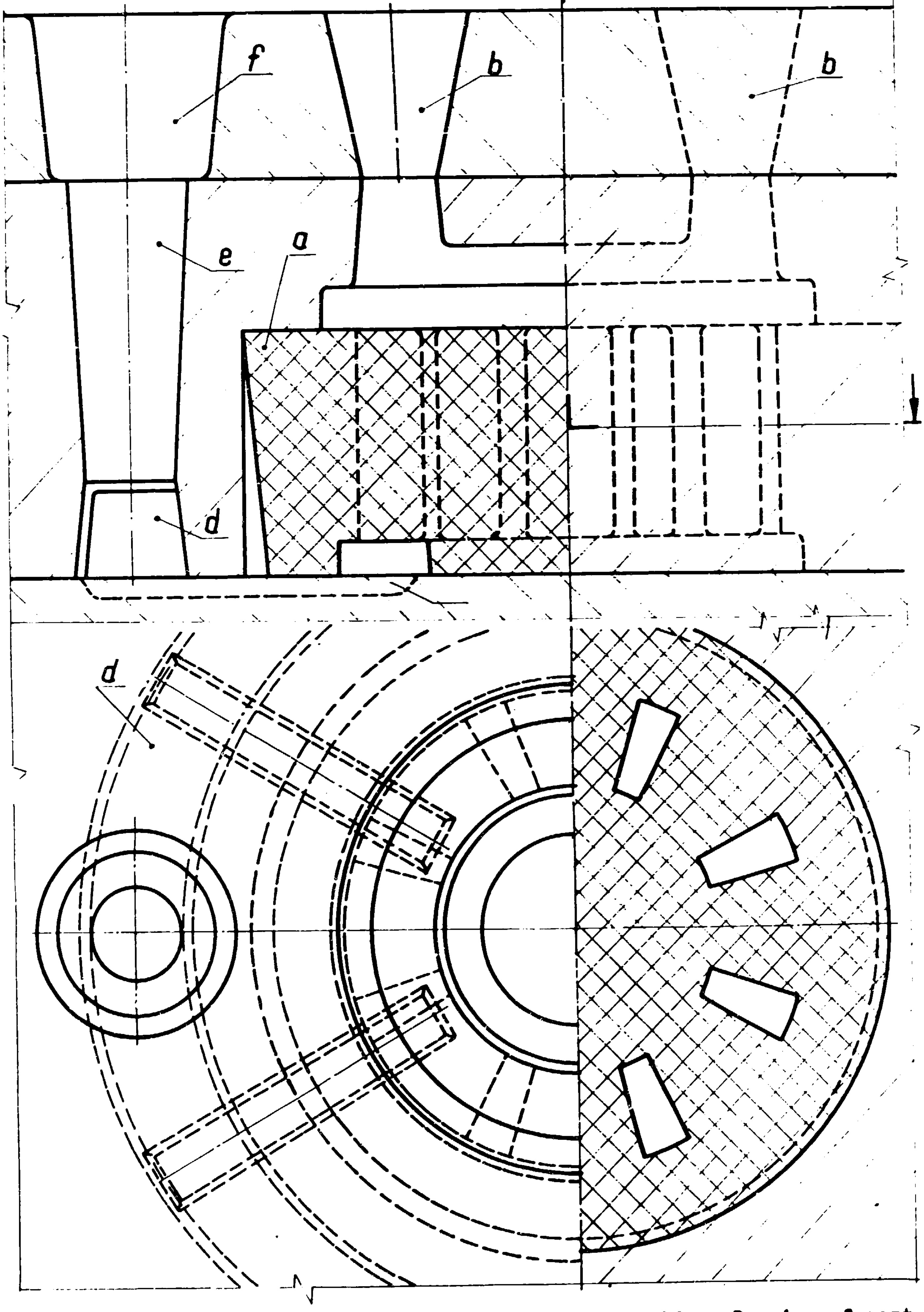

Fig. 7.10. Impeller of centrifugal shot blasting machine. Drawing of casting mould; a - core, b - feeder head, c - gate runner, d - runner, e - downgate, f - pouring basin

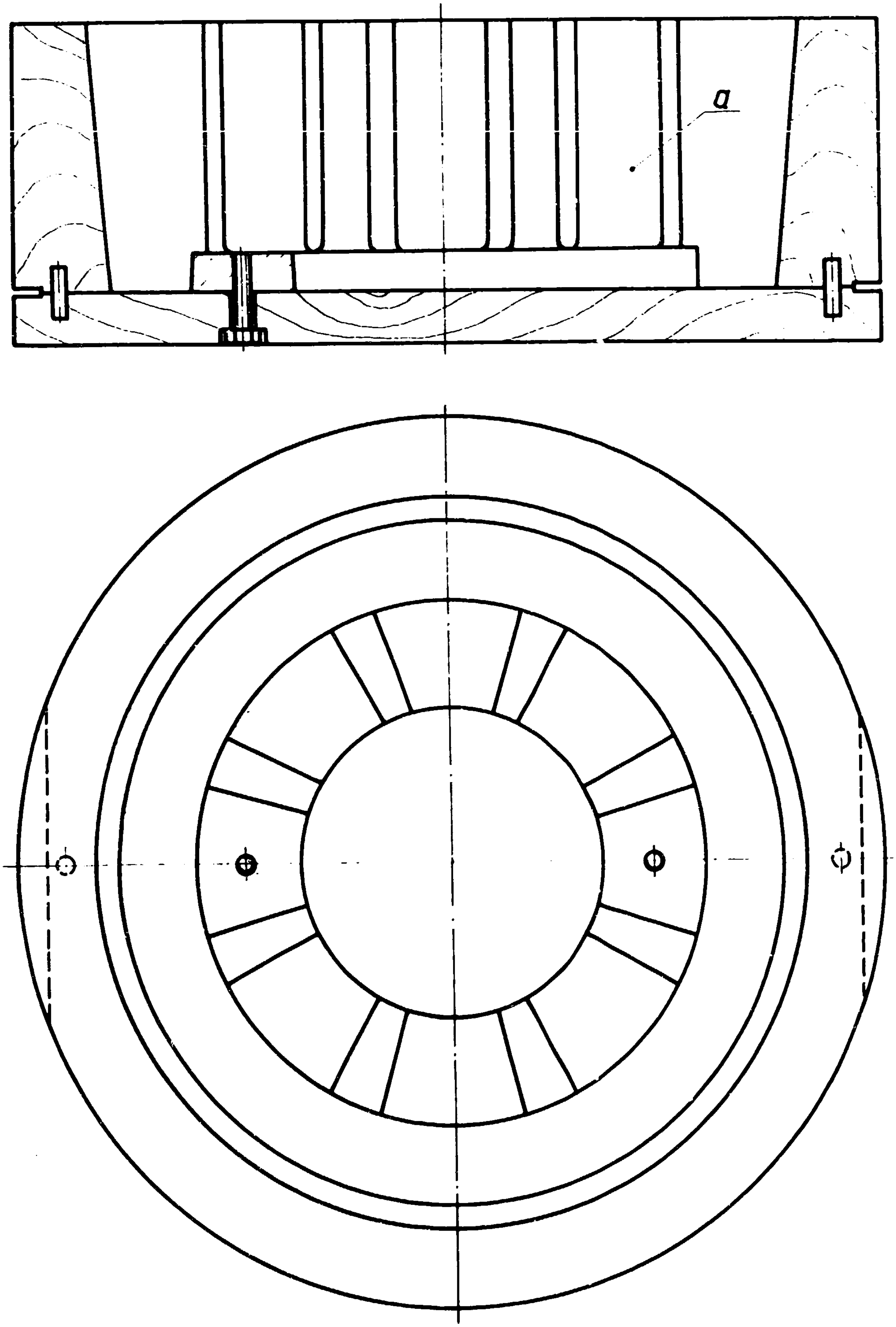

Fig. 7.11. Impeller of centrifugal shot blasting machine. Drawing of core box. Central part of the core box /a/ is a fragment of the casting out in plane C–C /see: Fig. 7.9/

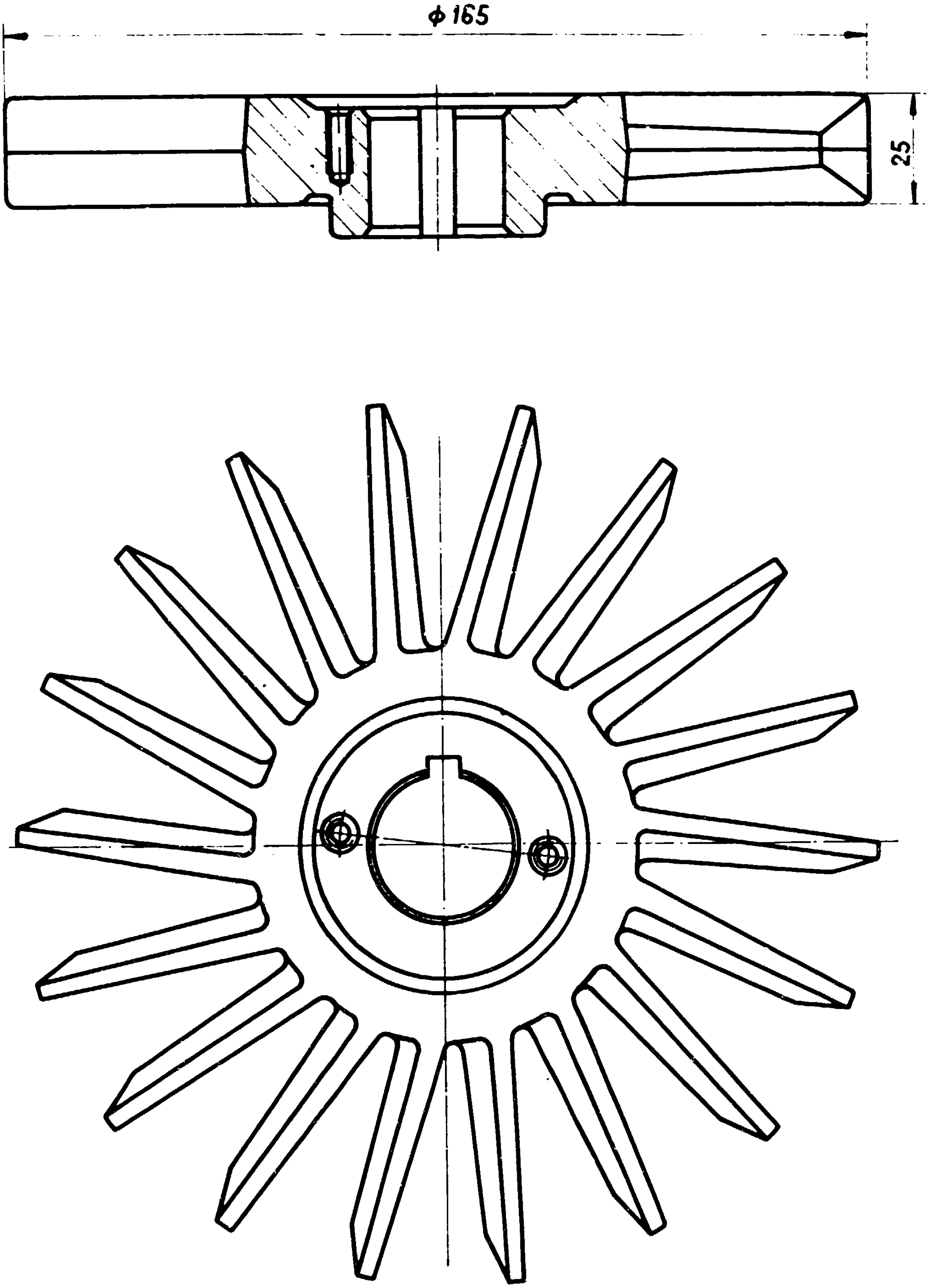

Fig. 7.12. Pump impeller cast in grey iron with flake graphite

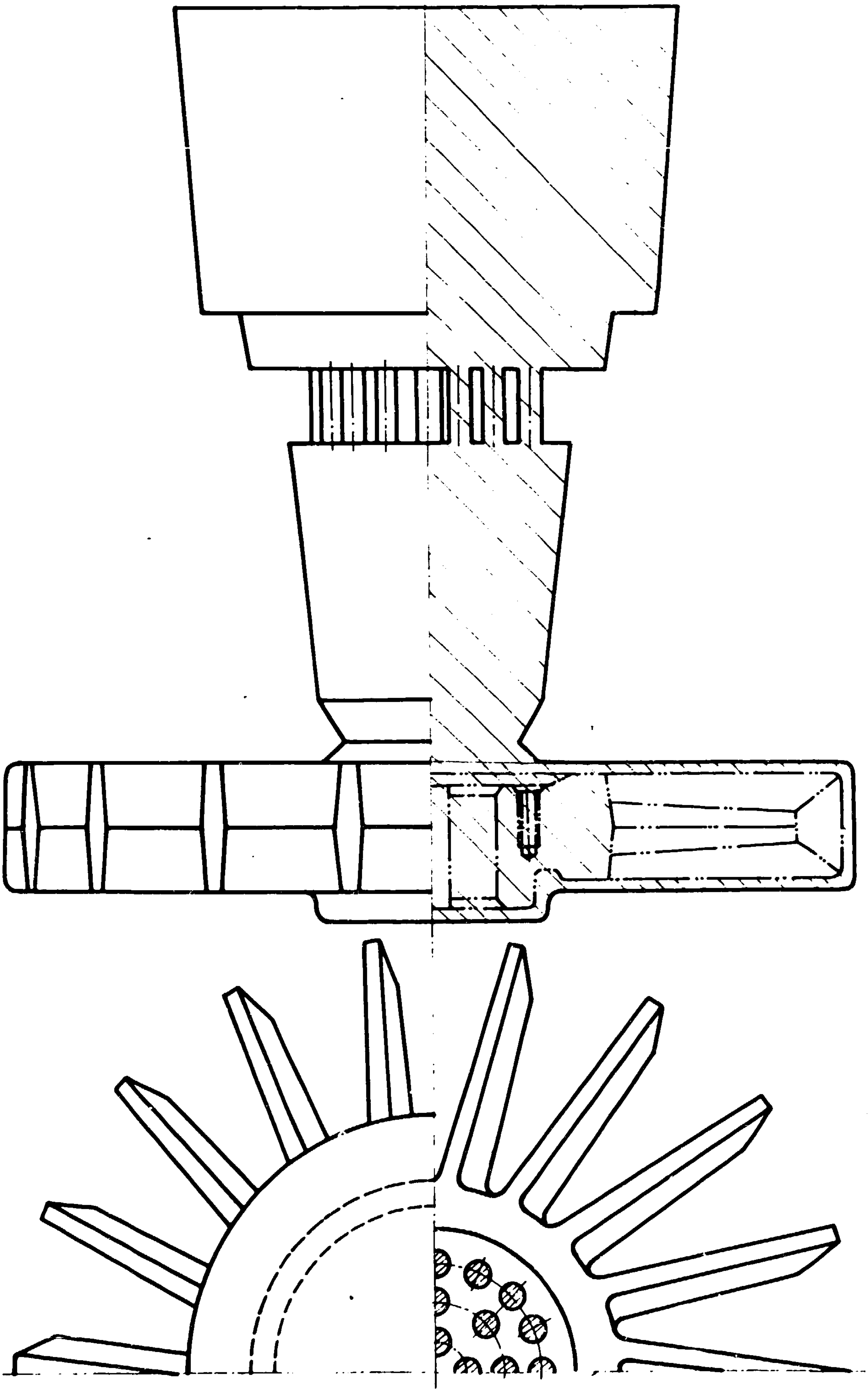

Fig. 7.13. Pump impeller. Drawing of casting with machining allowances and gating system

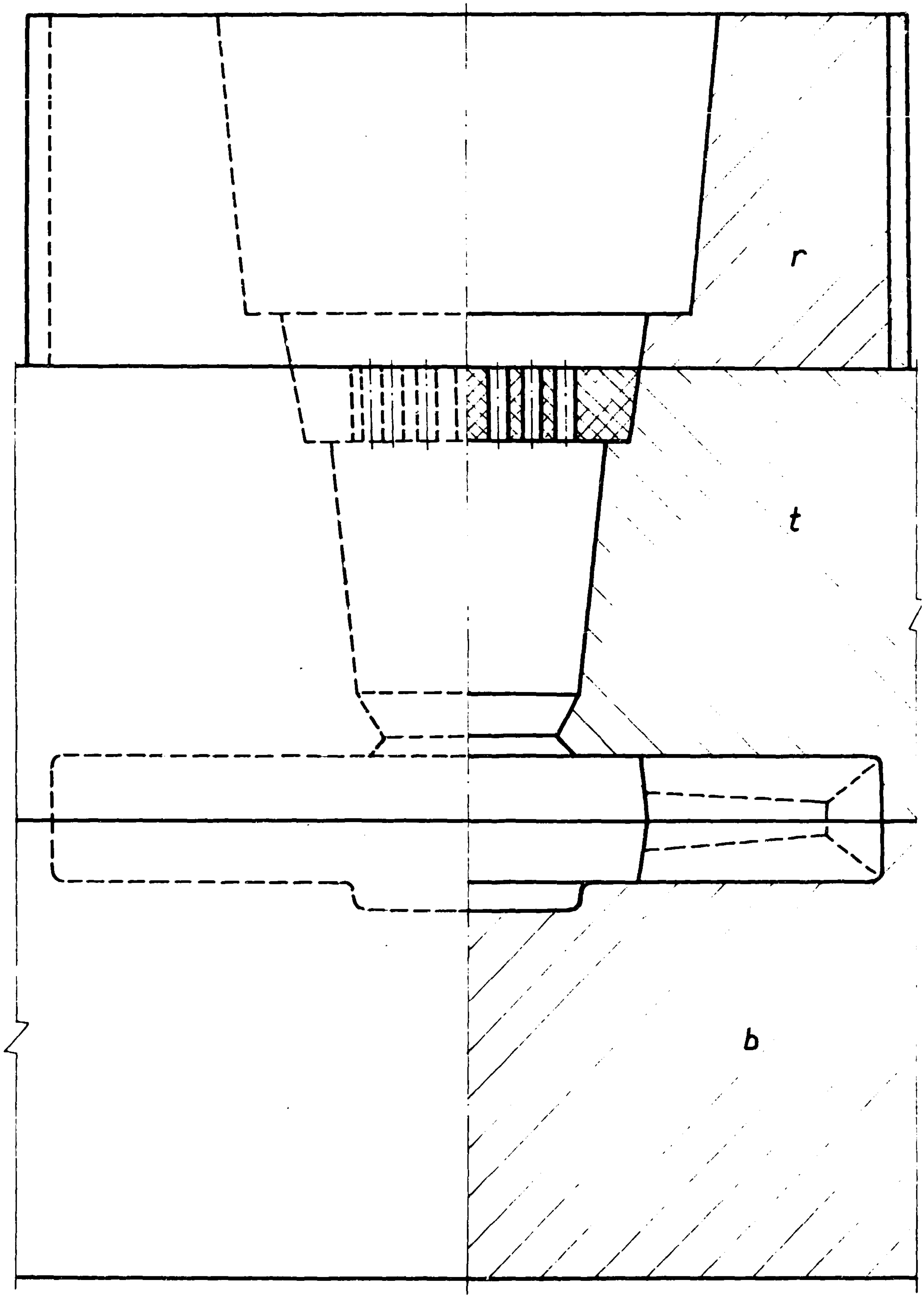

Fig. 7.14. Pump impeller. Drawing of casting mould; b - drag, t - cope, r - runner bush

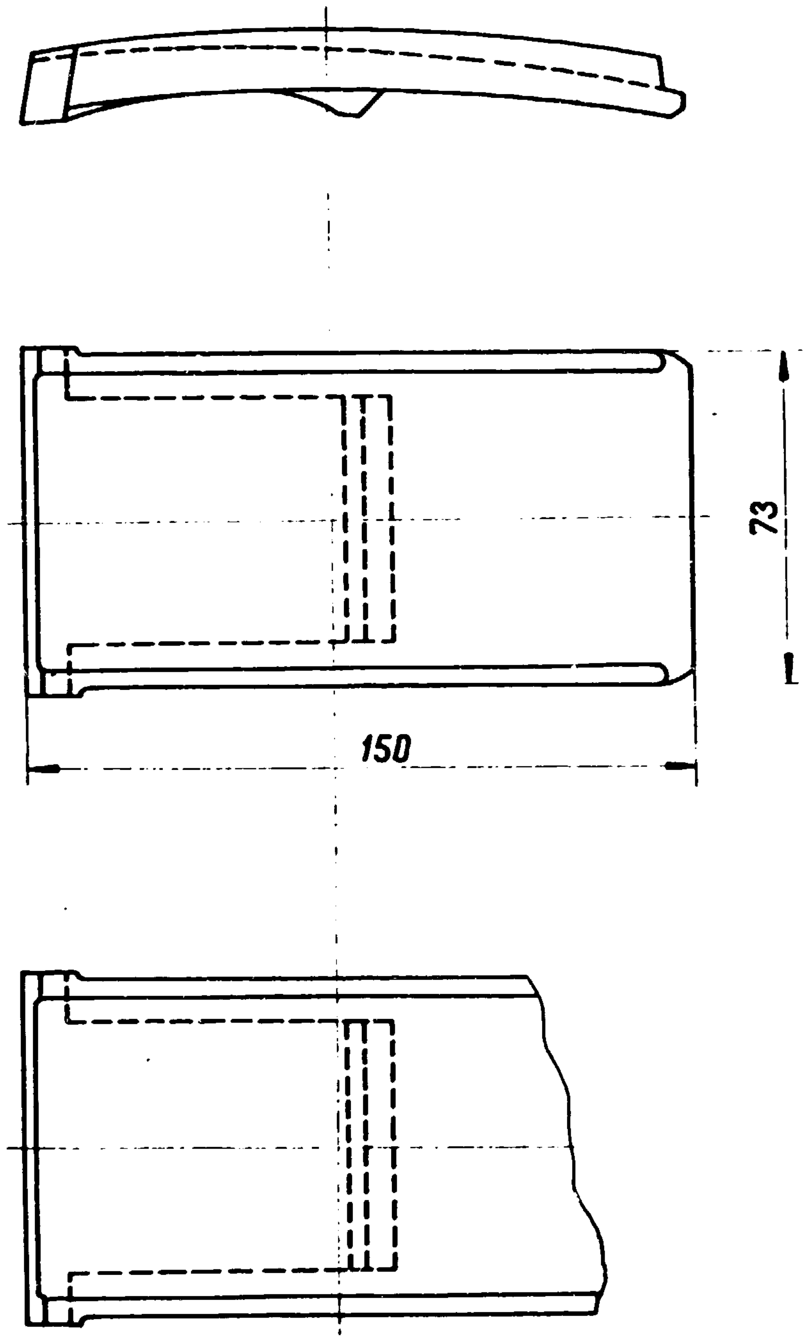

Fig. 7.15. Blade for centrifugal shot blasting machine cast in iron with addition of chromium. Drawing of casting. Note in the lower part of the drawing the blade worn during performance

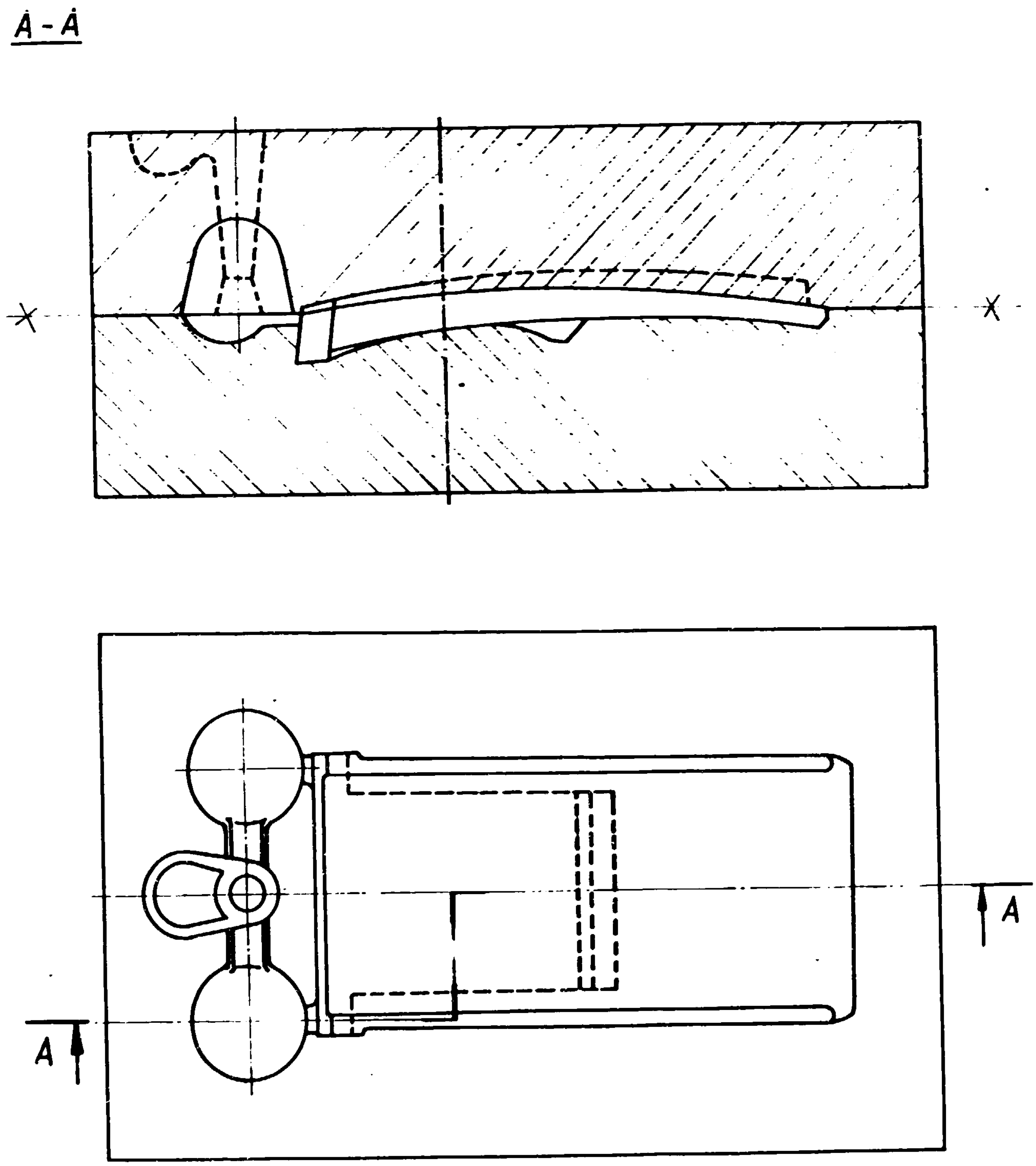

Fig. 7.16. Blade for centrifugal shot blasting machine. Drawing of casting mould

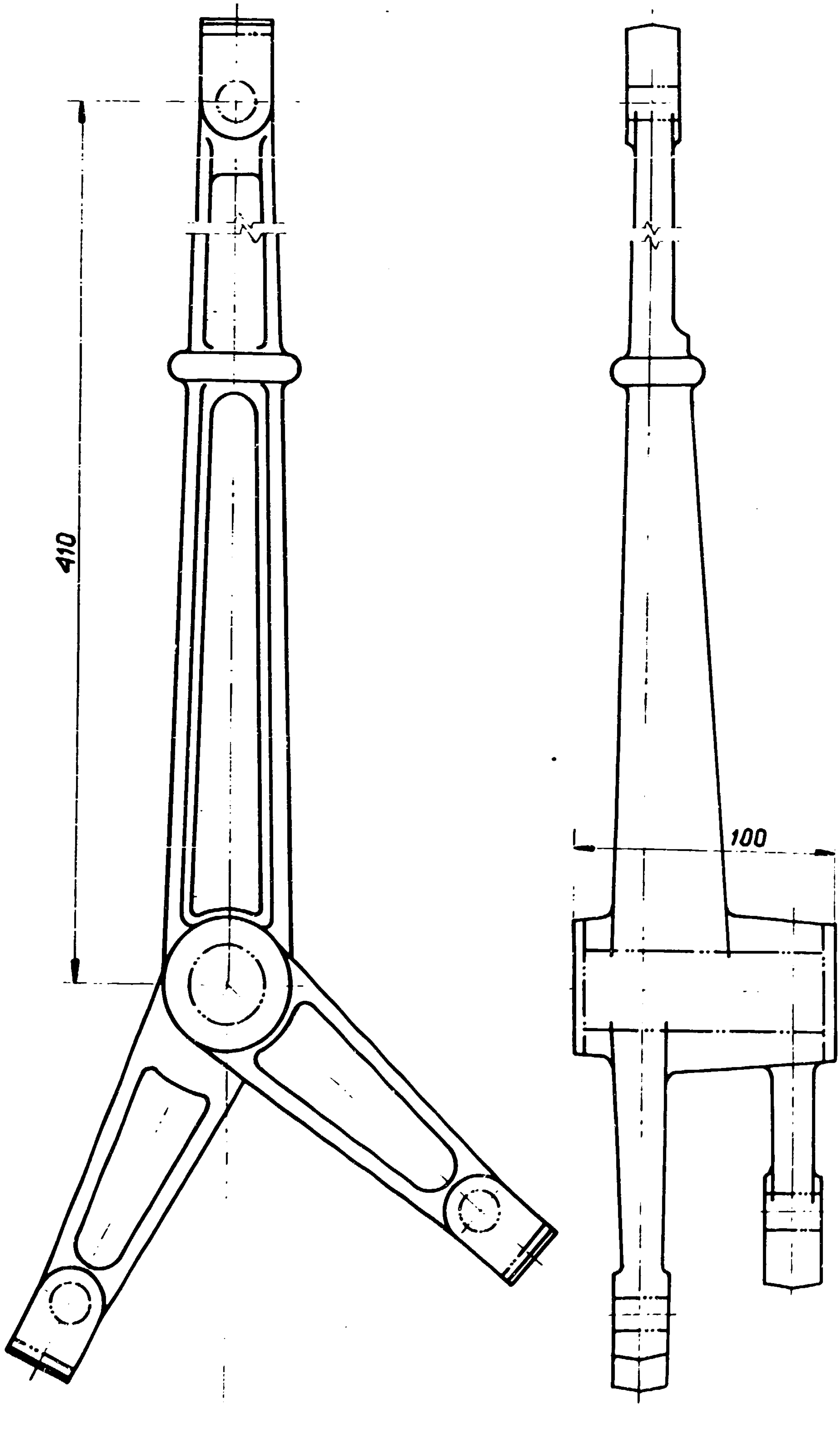

Fig. 7.17. Lever cast in Al alloy. Drawing of casting with machining allowances and technological allowances

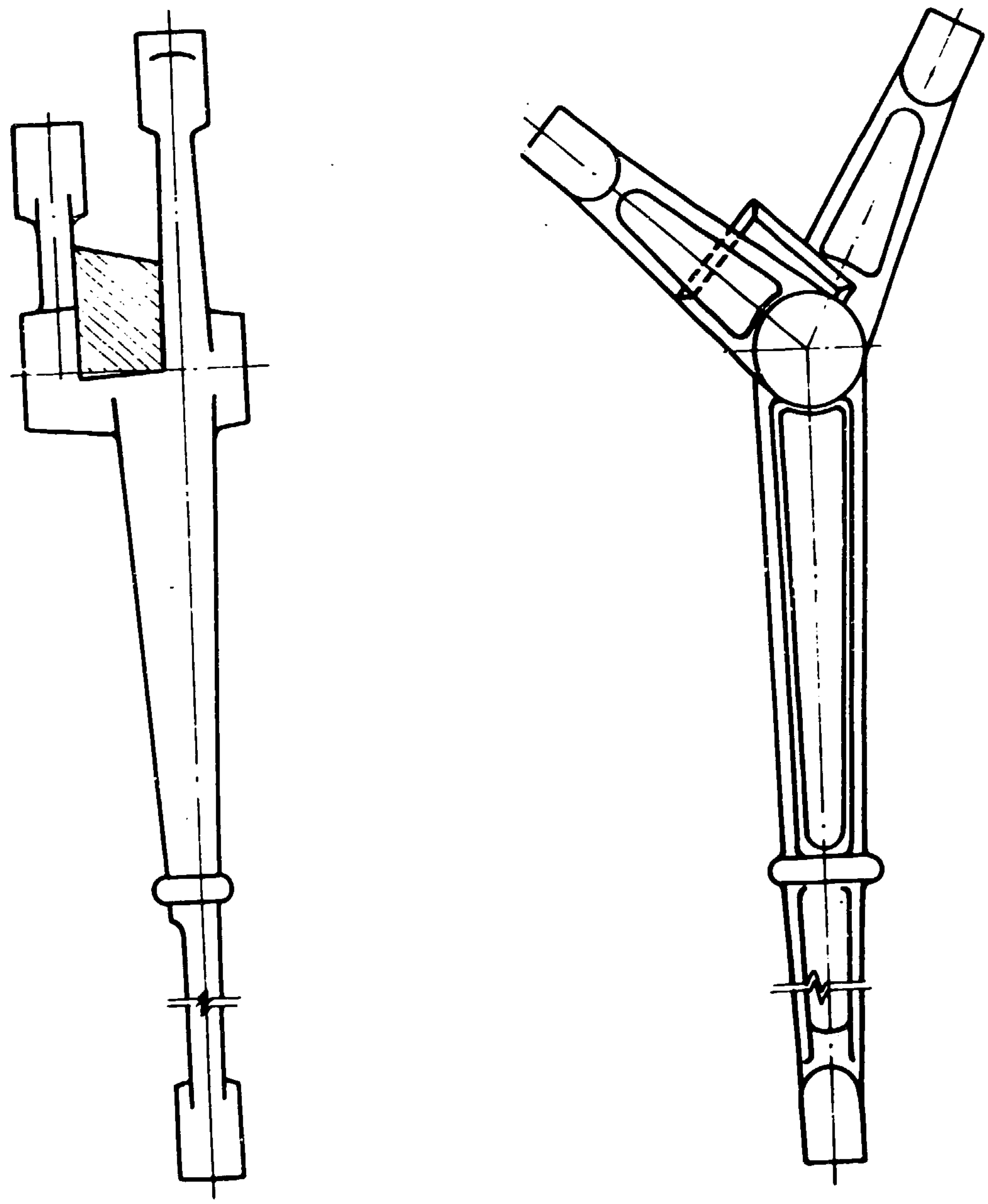

Fig. 7.18. Lever. Drawing of pattern

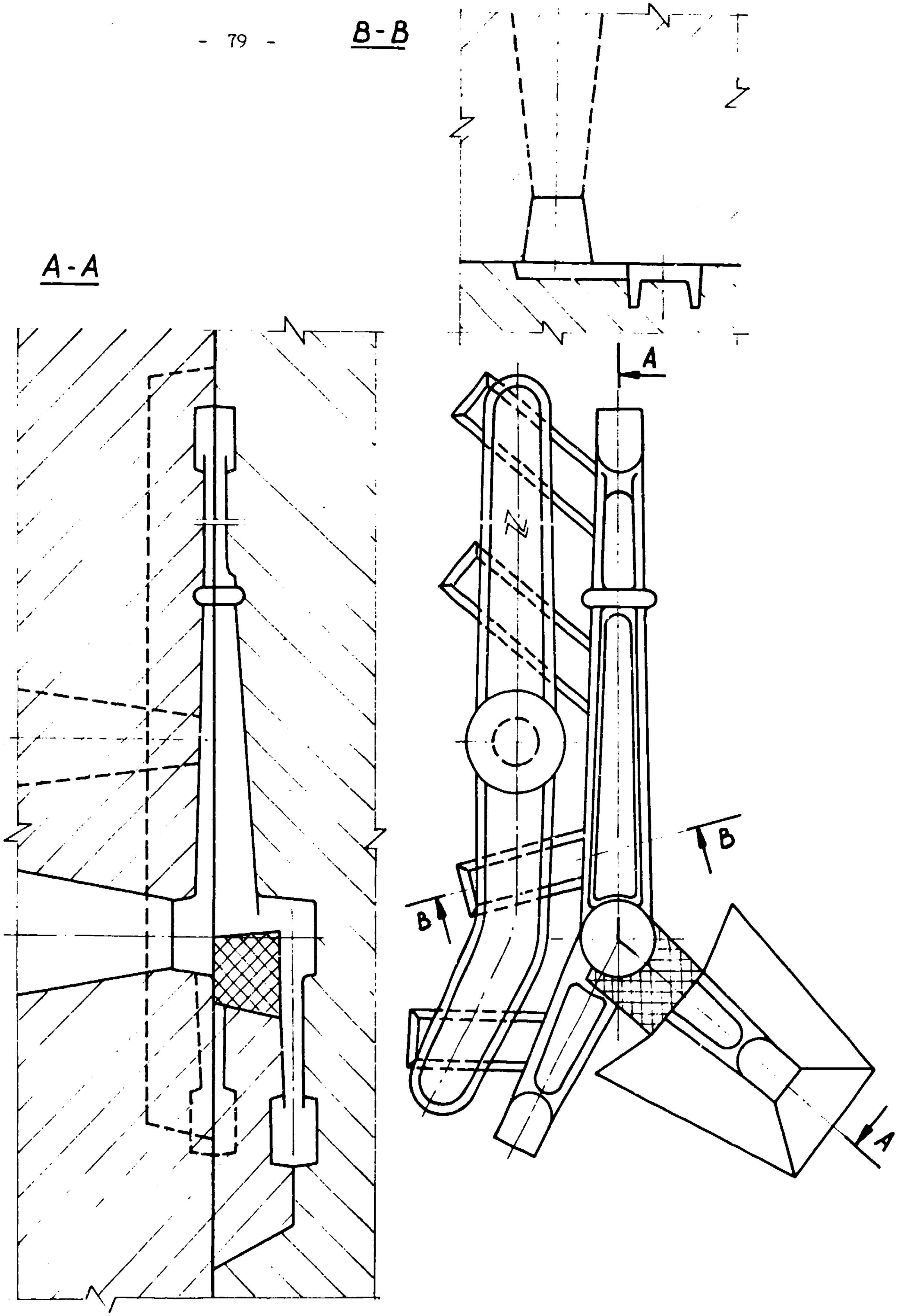

Fig. 7.19. Lever. Drawing of casting mould

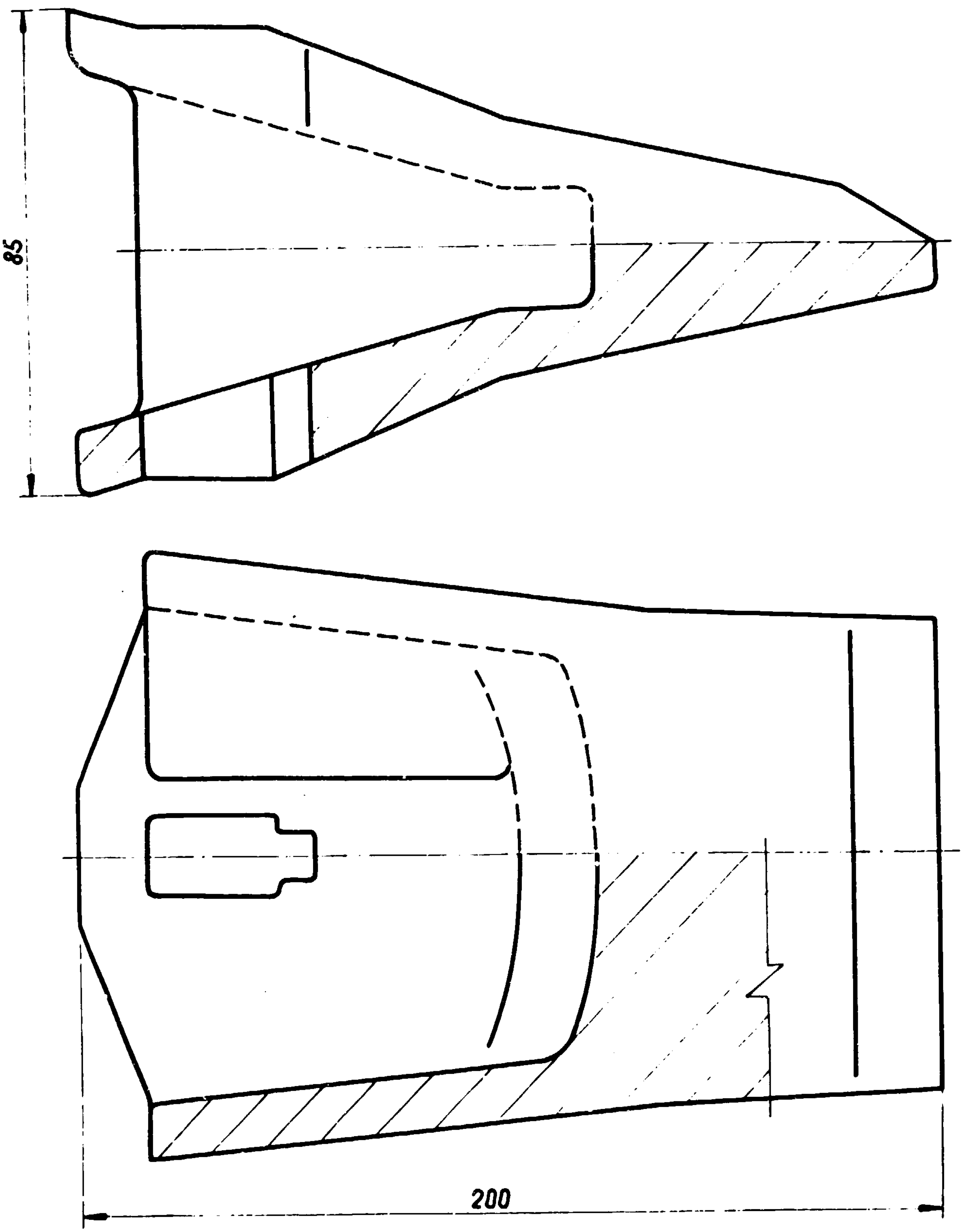

Fig. 7.20. Tooth for excavator cast in manganese steel

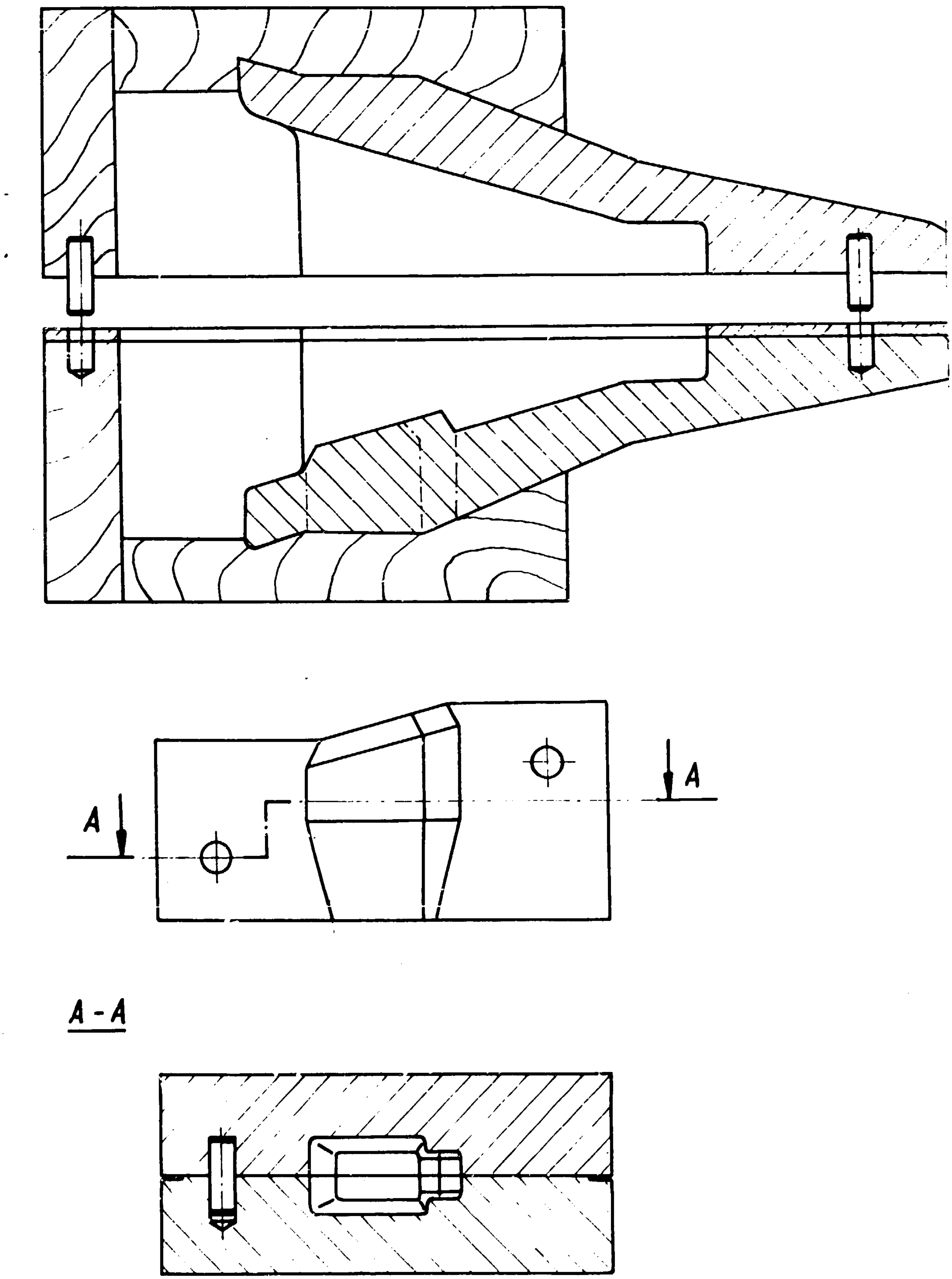

Fig. 7.21. Tooth for excavator. Drawings of two core boxes

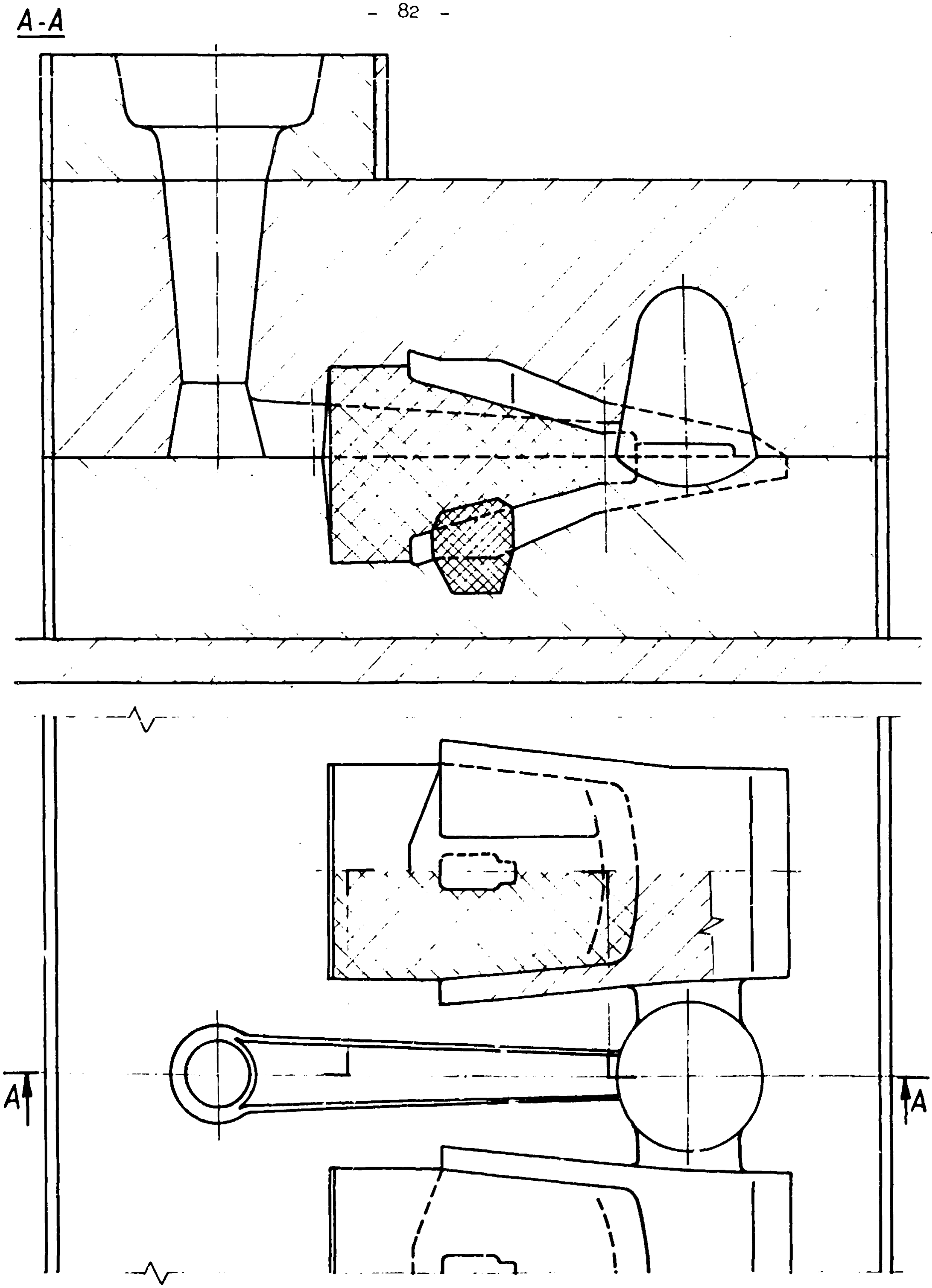

Fig. 7.22. Tooth for excavator. Drawing of casting mould

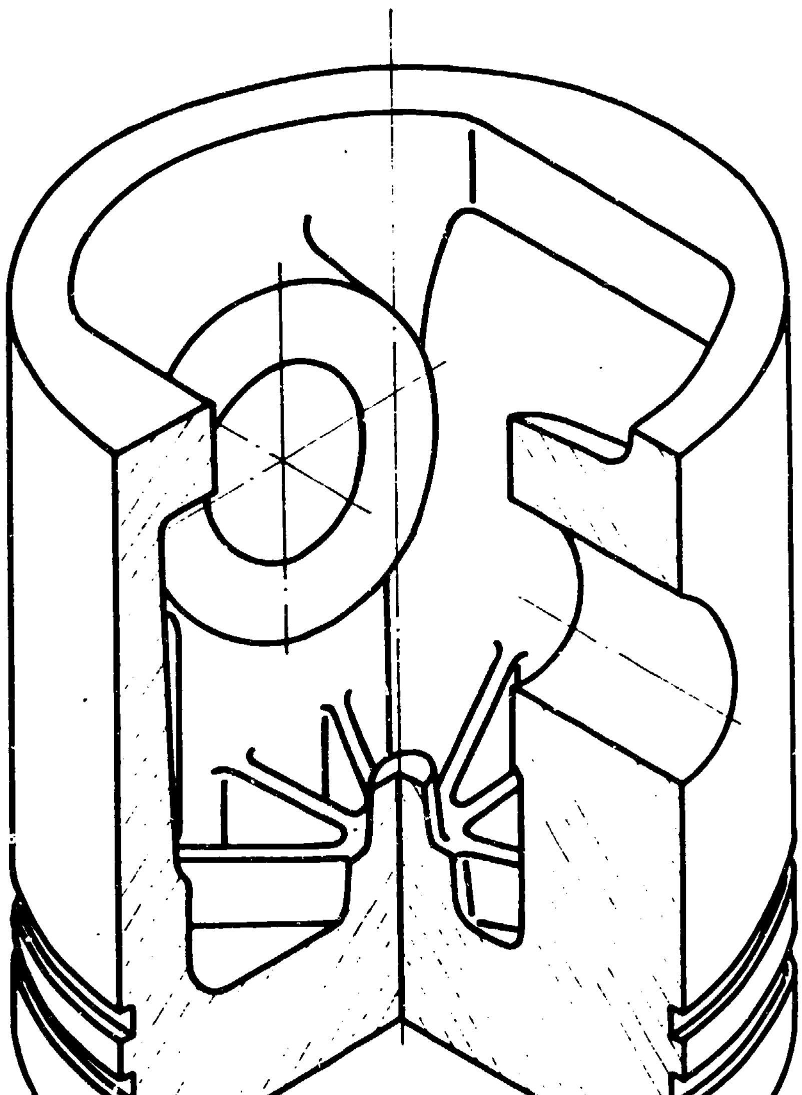

Fig. 7.23. Piston cast in Al alloy

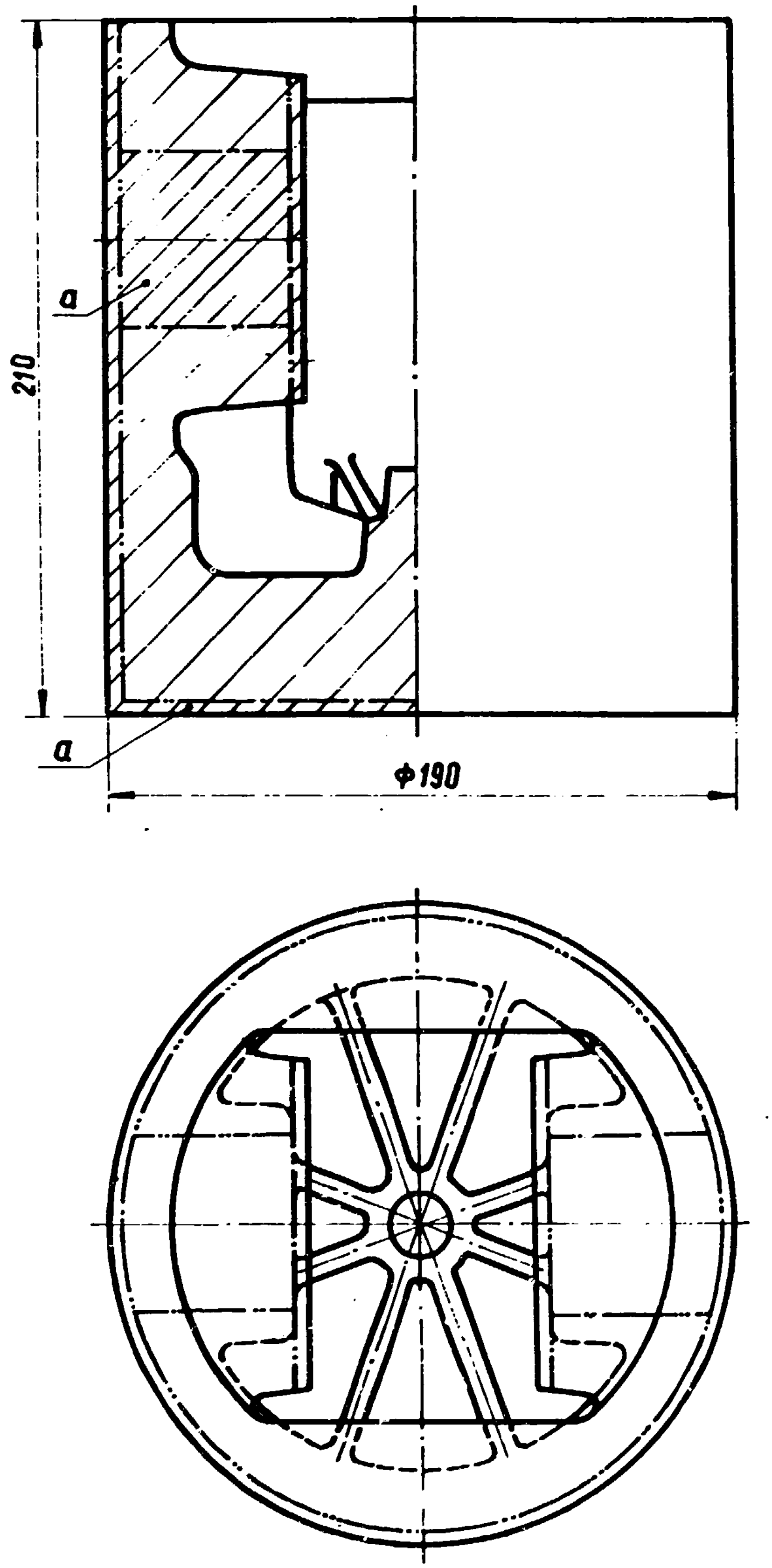

Fig. 7.24. Piston. Drawing of casting with machining allowances /a/

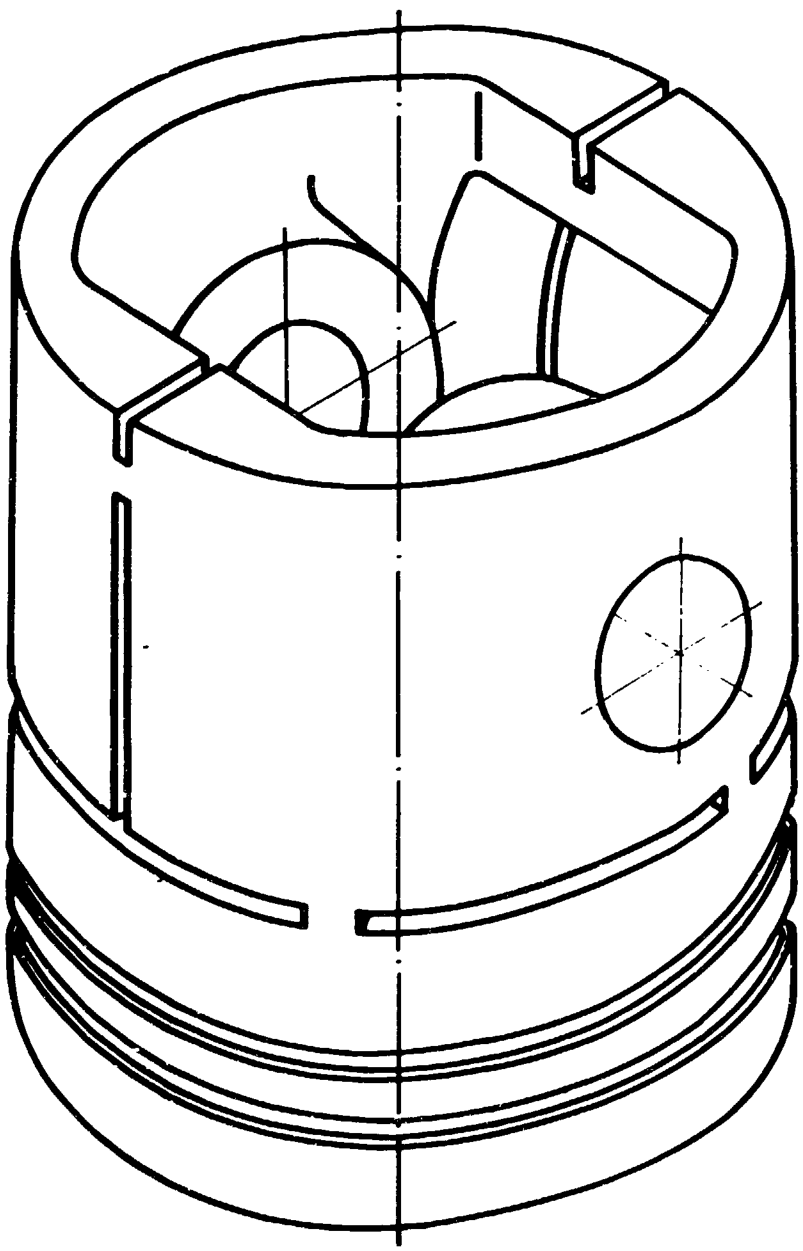

Fig. 7.25. Piston. Drawing of piston cuts to prepare a core box

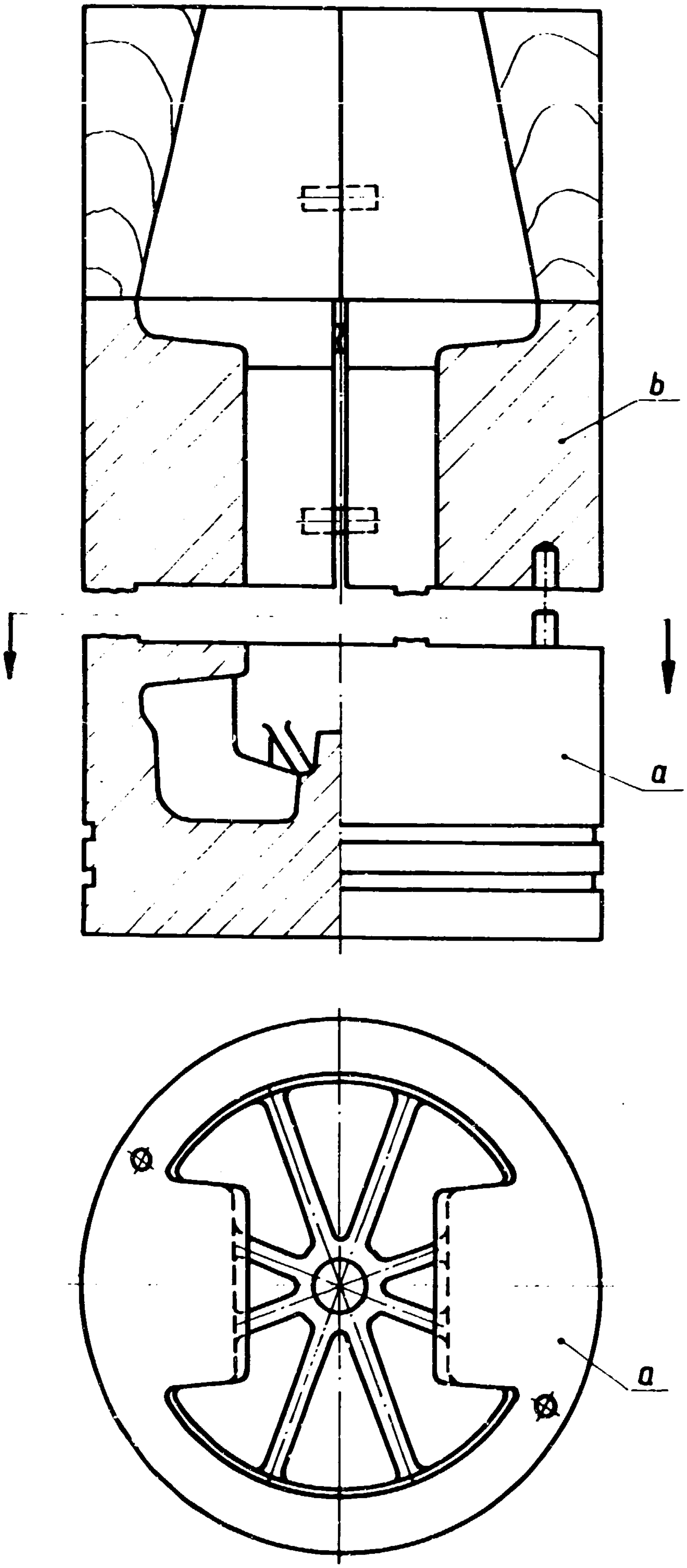

Fig. 7.26. Piston. Drawing of core box. Lower part /a/, half box of the top part /b/

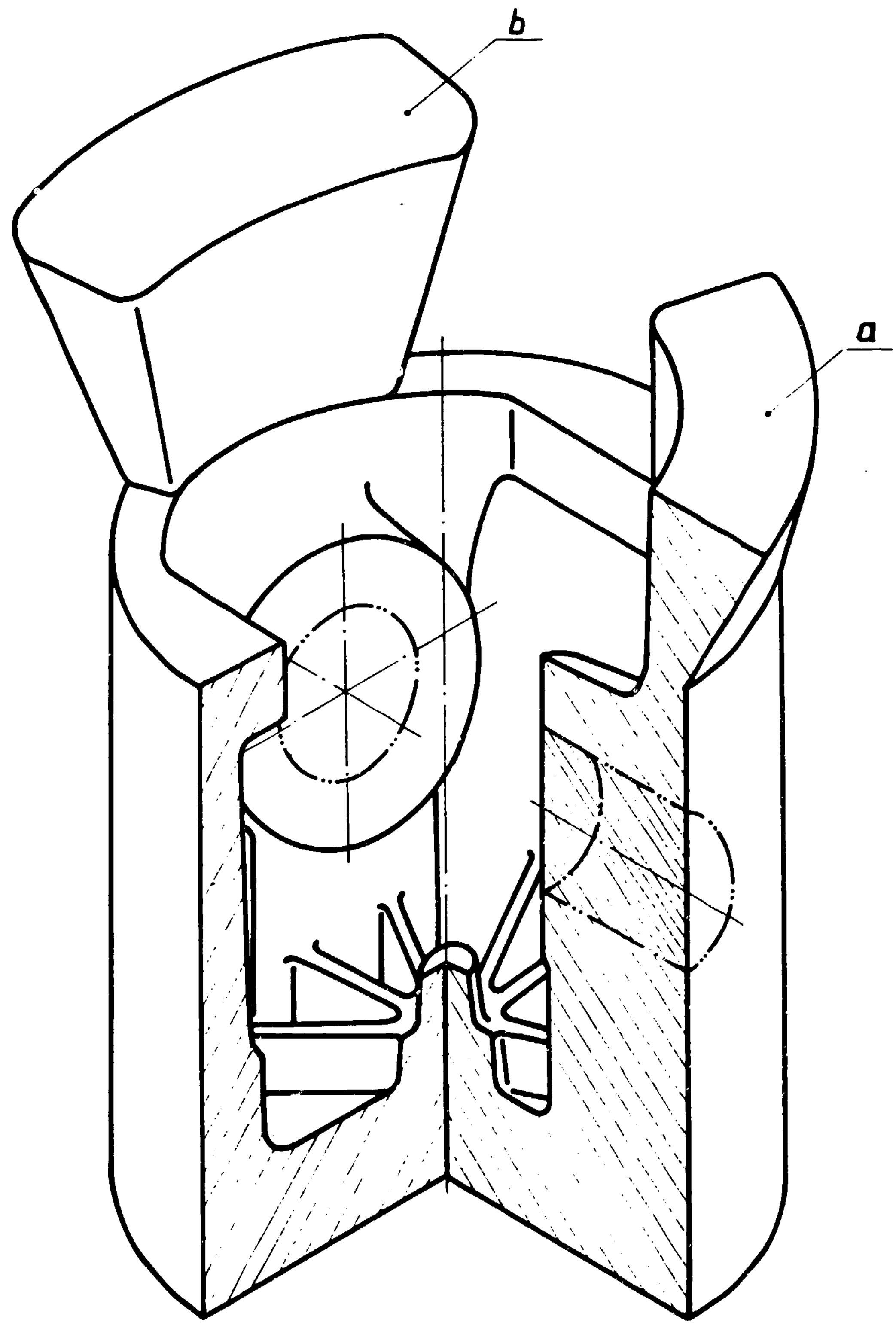

Fig. 7.27. Piston. Drawing of casting with feeder head /a/ and downgate /b/

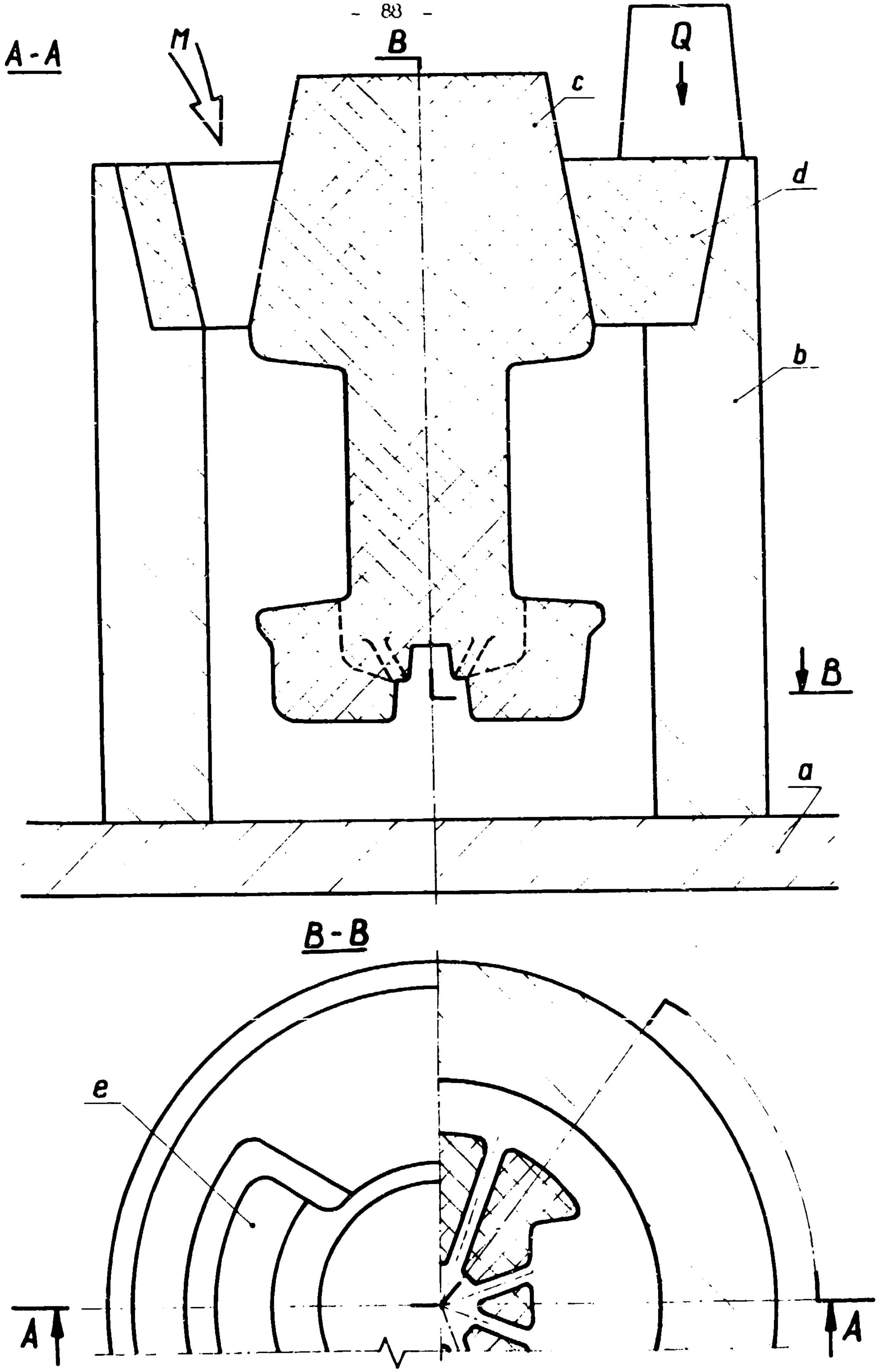

Fig. 7.28. Piston. Drawing of casting mould. Cast iron plate /a/, cast iron die /b/, central core /c/, locating core /d/, weight /Q/, downgate /e/

Appendix I

Table 3.1.

Casting materials

Alloy group	Typical alloying elements[1] /content in castings/	Main mechanical properties[2]			
		R_m MPa	$R_{0,2}$ MPa	A %	HB
1	2	3	4	5	6
Crey cast iron /with flake graphite/ including inoculated grade	2,7-3,8% C 1,2-2,7% Si 0,5-1,5% Mn 0,2-0,65% P 0,08-0,15% S	100- -400		0,2-3,0	100- -300
Spheroidal graphite cast iron, ferritic, pearlitic and mixed	3,0-4,0% C 1,3-3,7% Si 0,3-0,8% Mn 0,04-0,2% P 0,02% S	370- -1100	230- -800	2-17	135- -300
Whiteheart malleable cast iron	2,4-3,1% C 0,4-0,7% Si 0,3-0,8% Mn 0,1-0,15% P 0,1-0,2% S	350- -450	200- -260	4-12	200- -230
Blackheart malleable cast iron	2,2-3,0% C 0,8-1,4% Si 0,35-0,6% Mn 0,1-0,15% P 0,1-0,2% S	300- -350	190- -200	6-12	150- -160
Pearlitic malleable cast iron	2,2-2,6% C 1,2-1,6% Si 0,4-0,5% Mn 0,12-0,12% S	450- -800	270- -600	1-5	150- -310
Cast iron - - aluminium, - low-aluminium - medium-aluminium - high-aluminium including spheroidal graphite	5-9% Al;0-3% Cr 9,5-18% Al 19-31% Al;0-1% Mo	120-140 110-130 90-250			260-300 290-300 240-365

Table 3.1.

1	2	3	4	5	6
Chromium cast iron; low-chromium	0,1-2,7% Cr; 0-1% Al 0-0,4% Mo; 0-0,8% Cu 0-0,7% Ni; 0-0,35% Ti 0-0,3% V; 0-1% W	120-360			180-400
medium-chromium	6-18% Cr	about 350			about 450
high-chromium	18-36% Cr; 0-4% Al 0-9% Ni	300-480			2 0-540
Silicon cast iron -medium silicon spheroidal graphite	3,7-6% Si; 0-1% Cr 0-1% Ni	145-175 300-650	300-500		260-300 200-300
-high silicon	12-18% Si; 0-4% Mo	40-90			300-460
Manganese cast iron	7-12% Mn; 0-4% Al 0-4% Cu; 0-5% Ni	100-180			160-450
Nickel cast iron -low-nickel spheroidal graphite	0,4-2,5% Ni; 0-0,5% Cr; 0-0,9% Cu; 0-0,6% Mo	170-320 550-750	400-600	1-3,5	180-580 250-450
-medium nickel spheroidal graphite	2,5% Ni; 0,2-2,4% Cr 0-2,6% Cu; 0-1% Mo	170-180 600-1200	450-800	1-5	450-750 280-550
-high-nickel spheroidal graphite	12-36% Ni; 0-5,5% Cr 0-7,5% Cu; 0-1% Mo	170-280 370-700	170-550	0-3 1-45	120-250 120-250
Copper cast iron low-copper-spheroidal graphite	0,3-2% Cu; 0-0,4% Cr 0-0,8% Ni;0-0,13% Ti	190-270 550-750	400-550	1,5-3,5	240-290 250-320
Molybdenum cast iron-spheroidal graphite	0,15-1,4% Mo; 0-0,7% Cu;0-0,5% Cr 0-0,25% V; 0-0,1% Ti	150-320 660-700	400-500	1,5-3	190-270 200-280
Antimony cast iron	0,1-0,5% Sb	90-190			205-270
Titanium cast iron	0,1-0,2% Ti; 0-0,16% V	150-220			210-310

Table 3.1.

1	2	3	4	5	6
Vanadium cast iron	0,1-0,25% V	180			510
Constructional carbon cast steel	0,1-0,6% C 0,35-0,9% Mn 0,2-0,5% Si 0,05-0,09% P 0,05-0,07% S	400-650	250-380	15-26	114-223
Constructional alloyed cast steel	0,3-1,1% Cr 0,3-0,8% Ni 0-0,45% Mo 0,15-0,45% C 0,2-0,8% Si 0,5-1,6% Mn	550-880	300-700	12-18	160-260
Wear-resistant alloyed cast steel	0,3-3,2% Cr 0,2-2,0% Ni 0-0,6% Mo 0-0,3% V 0-0,3% Ti 0-0,3% Cu 0,2-1,4% C 0,4-14% Mn 0,2-1,4% Si	480-1200	320-900	4-21	134-410
Heat-resisting and creep--resisting alloyed cast steel	6-30% Cr 0-19,5% Ni 0,25-1,6% C 0,4-1,5% Mn 1,0-3,0% Si 0,04% P 0,035% S	400-550	250-300	0-25	155-350
Corrosion-resistantalloyed cast steel /stain less and acid-resistant	13-19% Cr 1-11% Ni 0-2,5% Mo Ti - depends on C 0,15-0,25% C 0,4-7% Mn 0,3-2,0% Si 0,035% P and S	450-650	200-450	8-25	130-280
Ferritic alloyed cast steel for operation at elevated temperatures	0,3-12,2% Cr 0-1,2% Mo 0-1,5% Ni 0-0,35% V 0-0,5% W 0,18-0,26% C 0,1-0,6% Si 0,5-0,8% Mn 0,03-0,035% P 0,025-0,03% S	440-880	245-590	15-22	

Table 3.1.

1	2	3	4	5	6
Superalloys Nickel-Base Alloys	0,05-0,5% C; 0-2% Mn 0-28% Cr; 0-15% Co 0-35% Mo; 0-18,5% W 0-2,5%Co; 0-4,7% Ti 0-7% Al; 0-0,6% B 0-1,5% Zr; 0-20% Fe 0-9% Ta; 0-6% Cu 0-2,5% V; 0-1,5% Hf 0-0,5% Re for limited group of alloys	100 h 1200°F / 700-1015 1000 h 2000°F / 23,8-51,8 300-360	300-393	6-15	155-250
Superalloys Iron-Nickel Base-Alloys	0,08-1,05% C; 0-5%Mn 0,1% Si; 20-28% Cr 5-8% Ni; 0- % Co 1-3,2% Mo; 0-3,25% W 0-2% Cb; 0-0,003% B 0-0,25% Ni; 0-3% Cu	100 h 1200°F / 427-476 1000 h 1500°F / 129,5-161			
Superalloys Cobalt Base Alloys	0,25-1% C; 0-1% Mn 3-29,5% Cr; 0-15% Ni 4,5-25% W; 0-2% Cb 0-1% Ti; 0-4,3% Al 0-0,027% B; 0-2,2% Zr 0-2% Fe; 0-0,5% Y 0-9% Ta; 0-2% Re	100 h 1200°F / 400 1000 h 2000°F / 23,8-44,1			up 700
Ni-Cu-Si alloys /Monel/	21-36% Cu; 0,4-4,6%Si 0,5-1,5% Mn;0-3,5%Fe 0-0,5% Co; 0-0,13% C 0-0,6% Zr	360-710	170-710	0-40	100-390
Ni-Cu-Sn alloys	35-43% Cu; 5-10% Sn 0-1% Zn; 0-3% Si 0-1% Fe	360-630	190-330	0-20	100-400
Ni-Cr-Fe alloy	12-20% Cr; 5-20% Fe 0,5-2% Si; 0,5-1,5%Mn Ti,Cu, 0,3-0,8% C,Zr Mo,W,Be,Co	420-520	230-310	2-15	150-200
Ni-Si alloy	up to 10% Si	250-280			400-500
Ni-Ti-Al alloys	4-6,5% Ti 2-5-3,5% Al	(740-1150)		(8-34)	
Ni-Be alloys	up to 3% Be Mo, W,Fe,Cu,Cr				

Table 5.1.

1	2	3	4	5	6
Ni-Al alloys	2-4,4% Al; 0,4-1% Ti up to 1% Si 0-0,6% Mn 0,05-0,5% C				
Mn-Cu-Ni alloys	27-28% Cu; 11-12% Ni 0-0,3% C; 0-4% Fe 0-4% Si	400		10-15	110-140
Refractory Metal Alloys Molybdenum Base Alloys /arc melting/	0,5% Ti; 0,08% Zr 0,015 % C	315			
Copper	Not over 2% total. of As, Zn, Cd, Si, Cr or other elements	175-(370)	63-(280)	(11)-40	44-(105)
Red brass leaded red brass /> 0,5% Pb/	2-8% Zn Sn, Zn	224-259	70-119	25-35	35-60
Yellow brass Leaded yellow brass /> 0,5% Pb/	>17% Zn 0-6% Sn under 2% total of Al, Mn, Ni, Fe or Si	238-455	70-161	15-40	45-90
Semired brass Leaded semi-red brass /> 0,5% Pb/	8-17% Zn 0-6% Sn	196-252	98-105	26-30	55-60
High-strength yellow brass Leaded h.y.b. />0,5% Pb/	>17% Zn over 2% total of Al, Mn, Sn, Ni und Fe <0,5% Si; < % Sn	497-805 455-595	196-581 175-294	15-30 20	70-120 90
Silicon brass	>0,5% Si >3% Zn	385-595	168-350	21-30	90-115
Tin brass	> 6% Sn Zn>Sn	238-266	84-91	35	45-50
Nickel brass /nickel silver/ Leaded nickel brass />0,5% Pb/	10% Zn Ni in amounts sufficient to give white color	245-266	119	20	55-70

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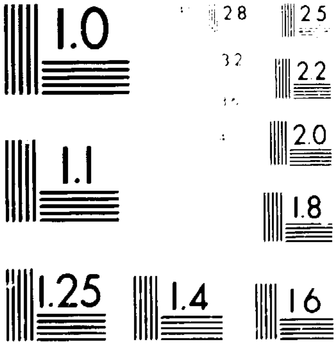

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS

STANDARD REFERENCE MATERIAL 1010a

(ANSI and ISO TEST CHART No. 2)

Table 3.1.

1	2	3	4	5	6
Tin bronze Leaded tin bronze / > 0,5% Pb/ High leaded tin bronze / > 6% Pb/	2-20% Sn Zn < Sn event. Ni,P	224-315 280-329 175-245	112-210 140-210 84-154	0,5-30 1-30 7-20	70-105 65-80 48-60
Lead bronze Leaded Copper	30% Pb Zn Sn Sn under 10% event. Ag,Ni	60		4	20-25
Nickel bronze Leaded nickel bronze /> 0,5% Pb/ copper nickels	> 10% Ni Sn under 10% Zn < Sn event. Fe,Be,Co Mn,Al,Cr,Sb	315-525 315-385	175-254 168-280	10-28 15-20	140 100-170
Aluminium bronze	5-15% Al under 10% Fe < 0,5% Si event. Mn,■i	400-750 (595-940)	189-385 (294-476)	2-26 (8-15)	125-195 (174-230)
Silicon bronze	> 0,5% Si	200-490	224-280	6-25	90-145
Beryllium bronze	1,3-2,5% Be or Be plus metals other than copper; Co, Si, Ni	570-670 (1085-1155)	330-385 (910-1085)	20 (0-1)	(230-390)
Cobalt bronze	0,25-1,6% Co Ag,Ni, Be, Si	350-560 (665-1120)	140-315 (480-980)	20 (1-8)	
Special alloys	12-40% Mn; 0,5% Ni 1-2% Al; 0-24% Zn 0-1,5% Pb	385-567	175-252	25-34	110-130
	5-8% Mn; 20-25% Pb 0-1,5% Ni	160-170		8-12	52
	2-4% As; 18-25% Pb 0-2% Mn	128-169		7,2-15	36-55
	18-23% Pb; 1,8% Si	152-220		12-23	56-69
	1-32% Mn	250-480		3-41	
	12-25% Mn; 1-10% Al 0-14% Ni; 0-25% Sn 0-3% Fe	up to 680	up to 350	up to 25	up to 185

Table 3.1.

1	2	3	4	5	6
Zn-Al alloys	3,5-31% Al 0-3,5% Cu 0-0,05% Mg	150-300		1-2	65-100
Zn-Cu-Mn alloys	14-15% Cu; 19-24% Mn 0,5-1,5% Fe	570-550		9-19	
Zn-Cu-Pb alloys for slide bearing	up to 4,5% Cu; 2-2,5% Al; 0,5-1% Sn				
Zinc alloys Zn-Cd, low melting point	about 43% Cd				
Sn-Sb-Cu bearing metal	7-12% Sb;2,5-6,5% Cu	68-100	43-118	0,2-9	27-32
Sn-Sb-Cu alloys for pressure die castings	4,5-17% Sb; 2-6% Cu 0-33% Pb	55-115			23-30
Sn-Pb alloys soft solders	10-37% Pb; 0-11% Cd 0,15-0,9% Sb; 0-5% Zn Bi, Hg				
Dental tin alloys	0-4% Ag; 0-1,5% Bi 0-1% Cd; 0-26,5% Sb				
Tin alloys for utensils	2-9% Sb; 0-2% Cu				
Pb-Sb alloys - accumulators - fittings - plumbings /sealing/	 5-13% Sb 2,5-10% Sb 0,5-3,5% Sb				
Pb-Cu-Ni alloy /sealing/	57-63% Pb; 2,25-2,75% Ni rest Cu				
Pb-Sb-Ag alloys /for anodes/	9-10% Sb; 0,8-1% Ag				
Pb-As alloys /shooting shot/	0,5-1,6% As; 0-4% Sb				

Table 3.1.

1	2	3	4	5	6
-Pb-Sn-Sb alloys - soft solder - printer's metal - for pressure die castings	17-50% Sn; 0,25-0,5% Sb 2,5-12,5% Sn; 11-19,5 % Sb 0-25% Sn; 3-15% Sb 0-3% Cu	50-88			9-24,1
Pb-Sn-Bi alloys /low melting point/	12-30,5% Sn; 9,5-25,5% Bi; 0-13% Cd				
Lead bearing metals	0-20% Sn; 0-20% Sb 0-3% Cu; 0-1,8% Ni 0-7% As; 0-0,2% Te 0-2,25% Cd; 0-1,15% Ca 0-0,9% Na; 0-0,07% Mg 0-0,2% Al; 0-0,8% Ba Ag, K, Li, Hg, Sr, Cgraf				
Bi-Pb-Cd alloys /low melting point/	17-44% Pb; 5-38% Cd 0-42% Sn; 0-9,5% Sb 0-42% Zn; 0-30% Hg 0-21% In				
Cadmium alloys /bearing metal/	0-3% Ni; 0-2,25% Ag 0-3% Cu; 0-1% Mg				
Cd-Zn alloys /filler metal/	15-20% Zn				
Hg-Cd alloys /dental alloy/	26% Cd				
Al-Cu alloys	3,5-10,7% Cu; 0,35-3,5% Si 0-1,8% Mg; 0,05-2,3 % Ni 0,05-0,35% Ti	(130-300)	160-(220)	(1,5-4,5)	(55-95)
Hypoeutectic Al-Si alloys	3,5-6% Si; 0-0,9% Mg 0-1,3% Fe	(150-320)	(90-220)	(2-5)	(50-80)
Hypoeutectic Al-Si-Cu alloys	4-9,5% Si; 1-5% Cu 0-0,6% Mg; 0-1,3% Fe	(120-290)	(120-210)	(0,5-1)	(50-85)
Quasi-eutectic Al-Si alloys	9-13% Si; 0-1,2% Cu 0,8-1,3% Fe	(150-320)	(90-280)	(0,5-10)	(50-70)

Table 3.1.

1	2	3	4	5	6
Hypereutectic Al-Si alloys	17-26% Si; 0,8-1,8% Cu 0,5-1,3% Mg; 0,8-3,6% Ni 0-0,6% Cr; 0-1,2% Co	(190)	(150)	(1)	(95)
Al-Mg alloys	2-11% Mg; 0,5-1,5% Si 0,5-1,3% Fe	(150-280)	(100-190)	(1,5-6)	(55-85)
Al-Zn alloys	4,5-6% Zn; 0,2-0,7% Mg 0-1% Fe; 0,1-0,3% Ti 0,15-0,6% Cr	(200-250)	(150)	(1-5)	(80-90)
Aluminium alloys for slide bearings	0-8,5% Cu; 0-2% Si 0-6% Zn; 0-6% Fe 0-2% Sb; 0-1% Cr 0-2,5% Ni; 0-3% Pb 0-3% Ca				
Mg-Al alloys	4,2-10% Mg; 0-3% Zn 0-1% Si	(140-245)	(70-161)	(0-8)	(50-73)
Mg-Zn alloys	2,1-6% Zn; 0,6-0,8% Zr 0-3,2% RE /rare earths/; 0-3,2% Th 0-2,5% Ag	(140-280)	(91-185)	(1-4)	(50-81)
Mg-Zr alloys	0,6-0,7% Zr; 0-2,5% Ag 0-3,2% Th; 0-2,2% RE	(188-245)	(42-185)	(2,5-1,4)	(50-78)
Ti-Al alloys	4-10% Al;	470-815	359-752	6-22	
Ti-Mn-Al alloys	up to 4% Mn 4% Al	984-1090	914-1027	3-8	

Table 3.1. - notes

1. Quite often the range of the content of elements is given for the whole groups of alloys, which means that in a given range of contents there are some alloys which contain a given element in a more narrow range; f.ex. the range 0-1,2% means that some of the alloys may not have this element at all.

2. These are the values determined by the standards as the, so called, "minimum" ones, in other words, the values encountered in practice may be and are higher; in the scope of mechanical properties /R_m, $R_{0,2}$/ the values measured in practice are usually by 10-20% higher from the minimum ones; a similar situation occurs in the case of plastic properties /A/.
The value of hardness /HB, i.e. according to Brinell; pressure of a ball/ given in the Table is not to be considered as a minimum one but as a "nominal" one, which admits certain small deviations /lower or higher nominal value/, or as a maximum one /f.ex. for alloyed cast iron/.
The ranges of the values of mechanical properties are given for the whole group of alloys, and the specific alloys have a considerably lower range of values. It is also worth noting that the directions of the real changes in the mechanical and plastic properties are quite often contrary to each other /particularly in the case of ferrous alloys, but not only/, i.e. an increase in the strength brings about a decrease in ductility and vice versa.