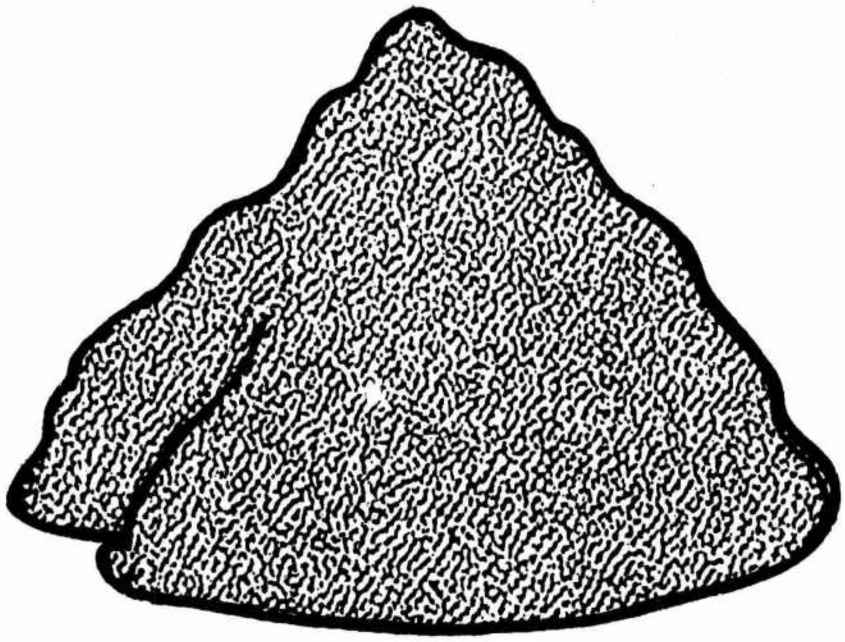
Review of THE POWDER METALLURGY PROCESS

U. S. ARMY PRODUCTION EQUIPMENT AGENCY
MANUFACTURING TECHNOLOGY DIVISION
ROCK ISLAND ARSENAL, ILLINOIS

JULY 1966

FROM POWDER



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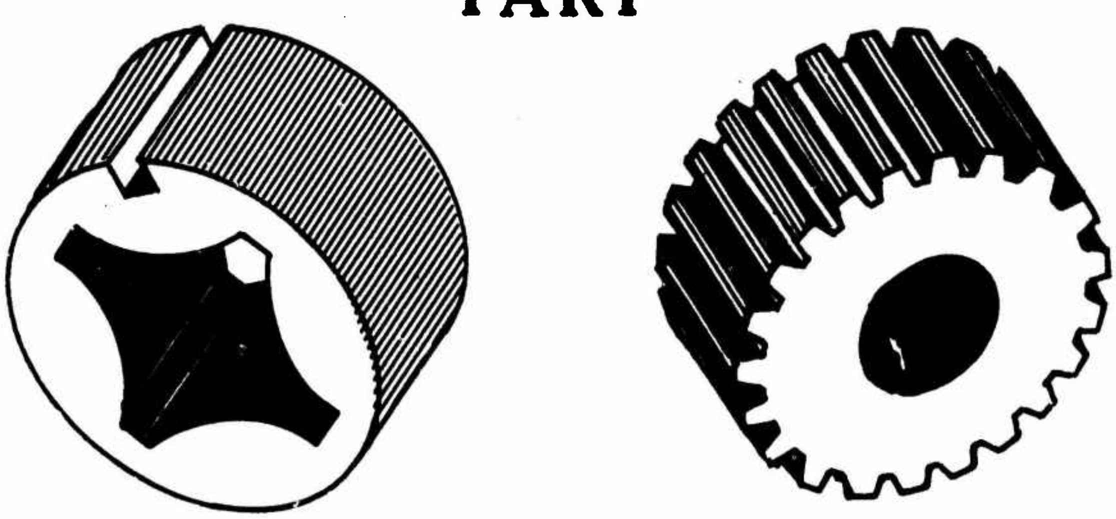
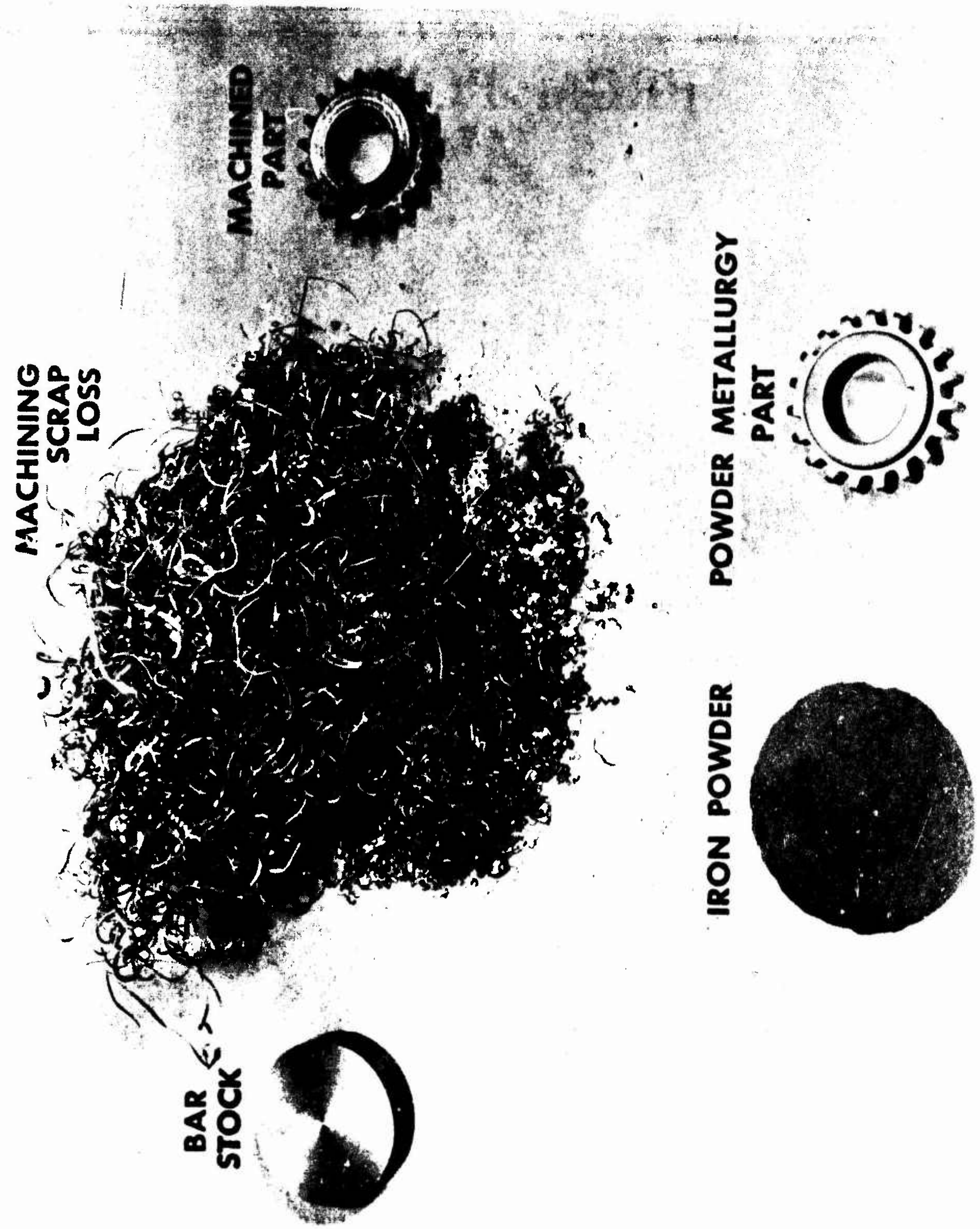
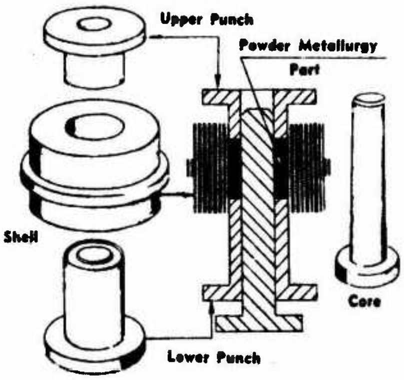




Courtesy of Metal Powder Industries Federation



Typical Die and Components

1 What Is POWDER METALLURGY?

Powder metallurgy is a process for producing metal parts by blending powders, compacting the cold mixture to the required contour, and then sintering or heating them in a controlled atmosphere to bond the contacting surfaces of the particles and obtain the desired properties in the part. Some parts are subsequently sized, coined or repressed, impregnated with oil or plastic, infiltrated with a lower melting metal or alloy, heat treated, plated or subjected to other treatments.

2 How POWDER METALLURGY Differs from Other Processes

The powder metallurgy process is unique in that (1) it does not involve the handling of molten metal, (2) it seldom requires subsequent machining or finishing operations, (3) it permits the rapid mass production of steel and other high melting metal shapes in precision dies, (4) it enables the working of metals whose manufacture otherwise would be uneconomical or impractical, such as beryllium, tungsten, and molybdenum, (5) it permits combining materials which cannot be produced in any other way, including dissimilar metals, nonmetallics, and materials of widely differing characteristics. Most of the materials remain solid during sintering and are therefore relatively unchanged. As a result, the product retains the desired characteristics of each. For example:

. . . Mixtures of copper, tin, iron, lead, graphite, and silica to make friction materials.
. . . Copper combined with carbon, as in electrical brushes.
. . . Ceramics and metals to form cermets.
. . . Carbides and other materials too hard or too brittle to permit any other method of shaping.

(6) another unique feature of the powder metallurgy process is that the density, or conversely, the porosity, can be accurately controlled over a wide range to suit specific requirements. Controllable density in a metallic structure is possible only through this technique.

In other areas powder metallurgy is not unique—it is simply an extremely effective method of shaping metal parts on a mass production, high reliability basis. **The process is competitive with sand casting, die casting, cold heading, drop forging, extruding, stamping, drawing, and machining from bar stock. Savings in labor and materials, elimination of capital investment in machines and overhead, reduction in lead time, greater end-product value, and better performance are often important factors in the decision for powder metallurgy. More specific features of the process are detailed on pages 8 through 12.**

In short, powder metallurgy is **the new dimension in materials technology.**

SUMMARY

The following is a current review of the Powder Metallurgy Process and its potential applications to the improvement of Army's complex design and production problems. To better evaluate and utilize the process it is necessary that a practical knowledge of the methodology and its applications is understood.

Powder metallurgy is that methodology whereby solid metallic parts of required size and shape are produced from metallic powders. The process involves the preparation and production of the metal powders and compacting and sintering of the P/M shapes.

Powder metallurgy is usually referred to as a process which produces parts at a lower cost per volume than conventional methods. This in essence is fact but it is erroneous to believe that the above conception of the production application of the P/M process is the absolute criteria for consideration or utilization. Powder metallurgy serves in many areas and its advantage is not based on lowest cost alone.

A few Army activities are currently utilizing the P/M process but its potential has not been accepted on a broad basis. Industry is using the process on a much larger scale for the production of many P/M parts used in items that our daily lives are dependent upon. The Automotive Industry, especially, has intergrated structural P/M parts in areas that once were thought the parts could not function and be relied upon. So it is to those in Army activities who are not sold on the methodology as a production technique or process that this journal is focused. It is hoped that the presentation will shade more light on the P/M process and encourage its use as a competitive or alternate production process for the design, production, and procurement of Army materiel. This is not to imply that the powder metallurgy process is a panacea for the solution of all design and production problems because, like any production process, it has limitations as well as advantages. Its many advantages and unique applications do demand consideration by personnel responsible to Army materiel problems as a competitive or alternate production process.

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1. Purpose: This journal is intended to emphasize and familiarize design, procurement and production activities of the Army Materiel Command with the basic concepts of the powder metallurgy process and its potential applications. It is especially addressed to those activities which are not presently utilizing the various applications and techniques of the methodology. The present state of the Art/Science is presented to encourage wider use and acceptance of the process where it can serve to improve the competitive base of the Production Base Support Program.

2. Scope: This review is primarily concerned with the potential application and limitations of powder metallurgy as a competitive or alternate process for the design and fabrication of Army materiel components.

3. Discussion:

a. History and Background: Powder metallurgy is not a new process. It is believed to be the oldest form of metalworking and was used before metals were able to be melted down by high temperatures. The process has been used in one form or another for quite some time. One of the oldest references to the methodology is the iron pillar in Delhi, India. The pillar was made by forging together lumps of sponge iron. The pillar weighed six and one-half tons.[1]

Figure #1
Courtesy of Hoeganaes Sponge Iron Corp.

"Iron powder was probably first introduced about 1,000 A. D., when the Arabs and Germans made high quality swords out of oxidized iron powder. The powder was produced by filing forged steel lumps. After 'rusting', the

[1] Hoeganaes Brochure #133 5M 7/63

powder was again hot forged and the treatment repeated until the impurities were finely dispersed and the carbon content was sufficiently low. The best description of this process is found in the old German Saga of Siegfried."[1] Metallic powders have been produced and used for many years. One of the earliest uses has been in the decorative field. Gold particles were used extensively in the early renaissance period for this purpose. Wollaston in 1829 developed a technique to manufacture malleable platinum from platinum powder. This technique permitted the forging of platinum like any other malleable metallic material.

The manufacture of incandescent lamps is the first modern industrial application of the powder metallurgy process. Metallic powders of osmium, tungsten, vandium, zirconium, tantalum, and other metals were used to produce filament material for use in incandescent lamps. Tantalum and tungsten later replaced the above metal or wire materials for incandescent lamps. Tantalum produced from powder proved a successful filament material before the discovery of processing tungsten by the powder metallurgy process. Coolidge discovered that tungsten compacted and sintered from powder could be worked within certain temperature ranges and retain its ductility at room temperature. The discovery made possible the ultimate use of tungsten as the most successful filament material for incandescent lamps. Another of the early modern uses of the P/M process is the manufacture of sintered self-lubricating bearings. The lubricants are absorbed in the sintered bronze or brass under a vacuum. These bearings are used extensively by practically every known industry that has self-lubricating bearings applications.

Powder metallurgy is just beginning to exert itself as an industrial methodology for the fabrication of metallic and nonmetallic-metallic parts. Today the process is being utilized for many unique applications. Many of the reactive and refractory metals that otherwise could not be processed or alloyed in the wrought condition can now be fabricated into useful forms by the P/M process. Powdered metal parts are made in a broad range of ferrous and non-ferrous metals and alloys. Complex configurations with precise tolerances are produced in parts by the process. Desired mechanical properties can be obtained by several techniques or processes peculiar to the methodology. These parts often wear longer and operate more quietly under the same operating conditions as similar wrought materials.

Like all production techniques or processes, powder metallurgy possesses definite limitations as well as advantages and planning

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[1] Hoeganaes Brochure #133 5M 7/63

is indispensible for realizing optimum processing goals. It has frequently been found that parts usually made by machining, die casting, precision casting (investment), stamping, and other conventional processes can be considered for production by the P/M process and may prove to be more economical than the other methods.

The advancements in the scientific and technological fields have made great demands for new and improved materials. Often these materials have proven difficult to fabricate and process and require unconventional techniques for utilization. Powder metallurgy has been able to fill some of the gaps and opened the way to the solution of many unique and complex material problems. With the spectacular growth of the P/M Technology the process holds even greater promise for future applications and utilization.

At the present time, the methodology accounts for only a small percent of metallic parts compared with the tonnage produced by the usual conventional methods. But powder metallurgy has created a lot of interest among metalworking people and it is predicted and expected that a greater percent of P/M parts will increase day by day. Ultimately, the process will become a very important technique to the metalworking industry just as forging, casting, and other metal forming processes have become. The ingenuity of the metalworking industry, educational institutions, and government agencies can be counted upon to improve and promote the methodology to realize its great potential as the demand for metal, and metal-nonmetal parts increase. "'Powder Metallurgy is finally realizing its true status in metalworking,' says Kempton H. Roll, executive secretary, Metal Powder Industries Federation. 'The future is wide open.'

"The key to powder metallurgy's future is that it extends the design limits of liquid metallurgy. The ability to create products from tiny particles of matter--either by combining materials that defy uniform mixing in the molten state or by strictly controlling the structure--is breaking down traditional design barriers.

"'More and more structural applications are taking shape,' adds H. A. Wormet, President, Amplex Division, Chrysler Corporation. 'Thus, there will be a move to larger parts, higher strengths and higher density parts.'"[1]

"Other examples include: porous nickel electrodes for fuel cells and a tungsten rocket nozzle infiltrated with silver. In both cases,

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[1]Reprinted by special permission from Chilton Company from article "New Status, New Uses for Versatile Metal Powders" by C. L. Kobrin as published in the May 9, 1963, issue of <u>The Iron Age</u>, (C) 1963.

"pore size and spacing must be precise--to millionths of an inch for the electrode.

"'Such applications point up the new confidence in powder metallurgy,' adds Mr. Schwope. 'For years, aircraft designers shunned powder--"not reliable," 'they said. Now spacecraft and missiles rely on powder parts for protection, communications and guidance.'" [1]

The following is an excellent article by Mr. Arthur D. Schwope, Vice President and Technical Director, Clerite Corporation, Cleveland, Ohio.

"Powder Metallurgy is a Process"

"I suspect that many of us are limiting our concept of what powder metallurgy can do by thinking of it as a material rather than as a process.

"Powder metallurgy is in fact a unique process in the field of metalworking. It can be employed to manufacture articles of non-ferrous and ferrous metals from aluminum to zirconium as well as ceramics and combinations of the two. Tungsten wire used in light bulbs represents one of the early important uses of powder metallurgy. And today, useful forms of beryllium, tantalum, molybdenum, tungsten and rhenium are largely manufactured by powder metallurgy techniques.

"Powder metallurgy can produce shapes, dense or porous, without resorting to molten metal technology. Eliminating the liquid stage enables refractory metals to be processed without crucible or mold problems.

"Its other unique attribute is the ability to form complex shapes to tight tolerances. Parts can be made with such precision that subsequent machining or finishing is minimized or eliminated. Certain shapes can be made which would be uneconomical or extremely difficult to produce by any other method.

"It has been said by some representatives of government and industry that the powder metallurgy process does not produce parts with the reliability needed for industrial applications, whether in the air or on the ground.

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[1]Reprinted by special permission from Iron Age, May 9, 1963.

" I think this is a gross misconception. Powder metallurgy parts are playing important roles in the Polaris and Minuteman and in our space effort where reliability is a must. In fact, every day you and I place our safety in the hands of powder metallurgy. Consider the automobile: Brakes, buckles for seat belts, transmission gears, bearings, clutches, all contain powder metallurgy parts that are active load-carrying members. A typical 1965 automobile contains over 100 such items.

" Another popular misconception is that our industry includes many garage shop operators. There could be nothing further from the fact. The metal powder industry is made up of responsible firms, large and small, who are technically competent and who have a great depth of experience and know-how.

" I know of no progressive company that uses or produces metal components that is not active in powder metallurgy. Today, more parts are being produced by this method than ever before with powder consumption going up by 20% per year. The increase was 24% last year with shipment of some 73,000 tons of powder. Aggregate powder consumption will pass 200,000 tons by 1970, with 75% of this going into parts, according to estimates of the Metal Powder Industries Federation.

" The whole concept of materials is being altered by powder metallurgy. Today, materials and structures can truly be made to fit any design requirement."[1]

Such is a brief background of powder metallurgy and where it stands tody. It is a process in the field of metalworking and one that demands consideration.

b. Metal Powder Production: The powder metallurgy process begins with metal powders. Metal powders are discrete particles of solid metals and range in sizes from a fraction of a micron on up the scale to those that normally pass through a 20-mesh screen. The powders are produced by the following three general methods:

(1) Mechanical
(2) Chemical
(3) Physical

[1] Reprinted by special permission from American Society for Metals from the article "Powder Metallurgy Is A Process" by Arthur D. Schwope as published in the June 1965 issue of METAL PROGRESS, (C) 1965.

Because the various processes for the production of metal powders impart in them unusual properties and characterisitics unique to the individual process, a general discussion of these processes is presented. An explanation is given also as to why the products from the various production processes are referred to as reduced, electrolytic, or atomized powders. The pictures and literature used for illustration purposes are not intended to indorse any product or to convey the thought that the product used for illustration is superior to any product not illustrated. Many P/M parts manufacturers prefer to blend their own particular mix to obtain desired mechanical properties and production techniques for their parts.

The three main production processes for metal powders can be further subdivided into specific methods.

(1) Mechanical Processes: This method is subdivided into the following categories:

(a) Atomization
(b) Pulverization or Comminution

(a) Atomization is the process where molten metal is disintegrated into particles by pouring it into a jet stream of

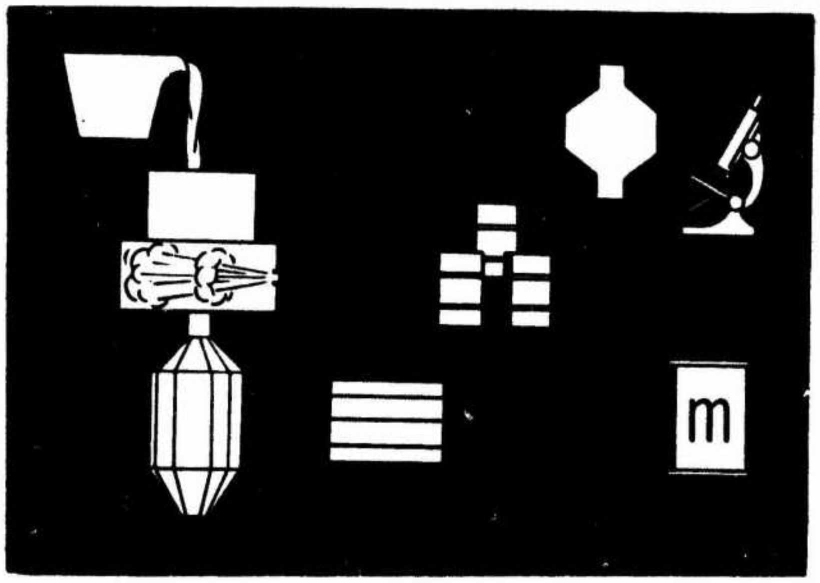

Figure # 2
Courtesy Metal Atomizing and Processing Corp.,Ltd.

air, inert gas, water spray, or steam. The jet streams are made by forcing the disintergrating mediums under pressure through a nozzle or an orifice. The jet streams bombard the molten metal into particles (Figure # 2). Careful control of the metal stream, spray medium or protective atmosphere, and pressure of the atomizing medium is important. The material is then dried and processed by other methods as the manufacturer deems necessary to produce his particular product. In some cases the atomization process is used as an intermediate method before the reduction processes are used. However, elemental powders can be produced by the atomization process under controlled conditions. A few powder manufacturers do use the process for producing high purity iron powder.

The atomizing process has been perfected into a versatile tool for the large scale production of ferrous alloys and non-ferrous powders. Usually the atomizing process is used where other processes cannot produce the desired alloy or metal powder. The process is practically the only successful method for producing prealloyed and certain refractory metal powders (Figure #3). One

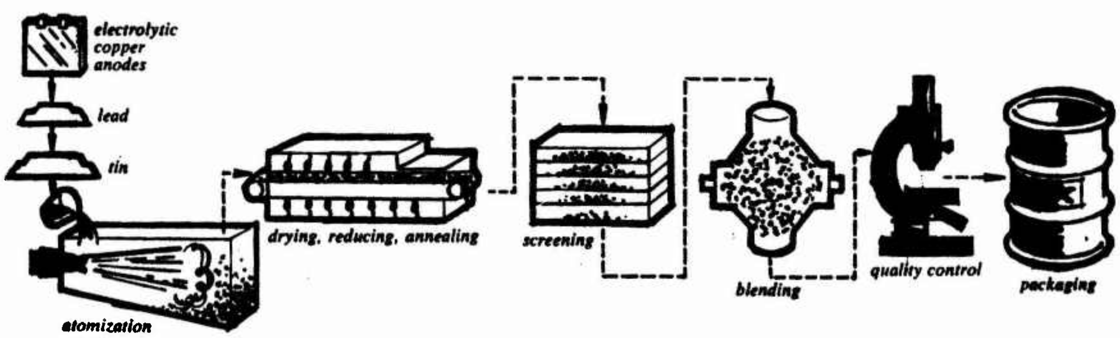

Figure # 3
Courtesy of American Metal Climax, Inc., Bull. MP/65-1.

unique use of the process is to produce aluminum-alloy powder for dispersion-strengthed materials. Prealloyed steel, tool steel, and stainless steel powders are produced by atomizing molten metal in a jet stream. Examples of stainless steel powder are shown in figures #4 and #5 .

Alloy steel powders that are atomized in a water spray or steam jet are dried and screened. The powders are heat treated in controlled atmospheres to reduce surface scales, control carbon content, and remove quench hardening effects. In stainless steel powders the surface oxidation can be overcome by the addition of silicon to the alloy. The addition of silicon also tends to produce dendritic type powders which improve compacting or pressing. The powder from this process is usually spherical or round in shape and can be porous or dense. (Figure #4)

TYPICAL SHOT PRODUCED BY THE
NUCLEAR METALS ROTATING ELECTRODE PROCESS

Figure # 4

Courtesy of Nuclear Metals Division of Textron, Inc.

"Making the Powder"[1]

"This process calls for pre-alloyed powder of high quality. Commercial atomization processes used for manufacturing stainless steel powder were considered best suited for this purpose. However, two problems developed during initial attempts to use this method. First, nonmetallic inclusions were picked up from erosion of

[1]Reprinted by special permission from American Society for Metals from the article "A New Stainless Steel From Powder" by E.F. Bradley, R. A. Sprague & W. B. Tuffin, as published in the September 1965 issue of METAL PROGRESS, (C) 1965.

"the atomization nozzle. Second, post atomization steps in the powder making process resulted in contamination by foreign powders. (These contaminating powders had been produced in the atomizer before making NM-100 powder.)

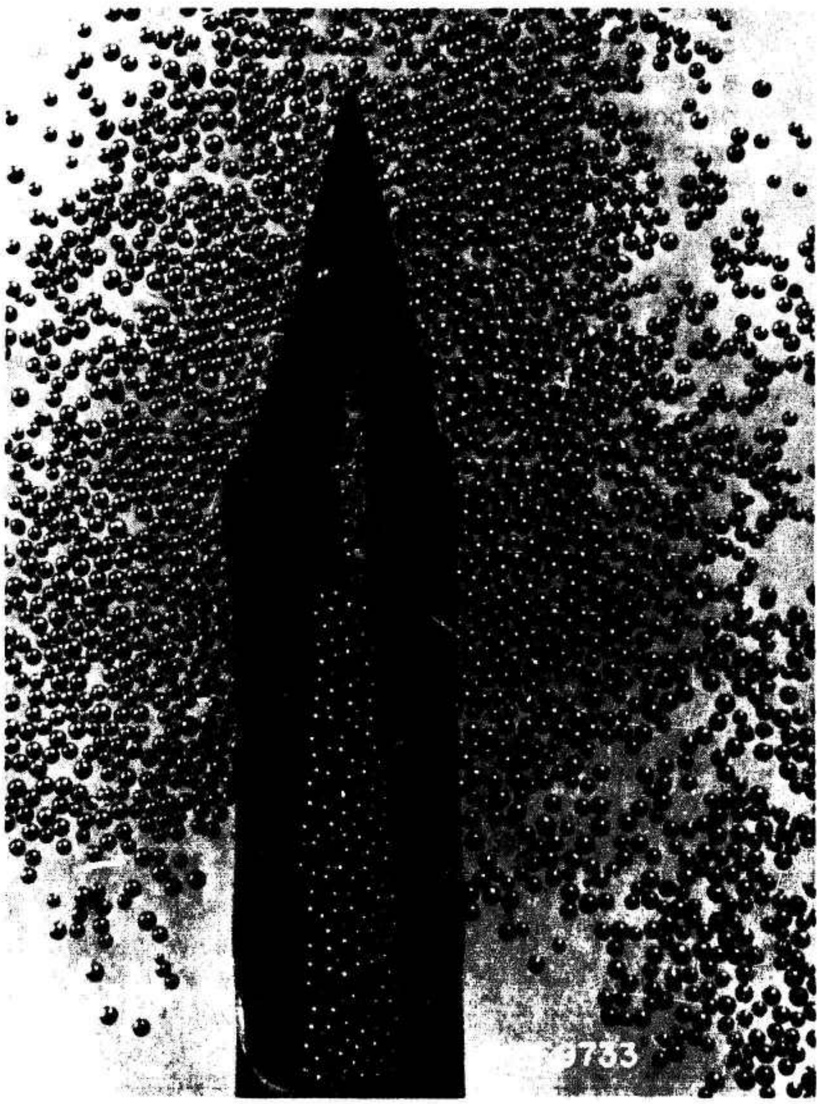

Figure #5
Courtesy of Nuclear Metals Division of Textron, Inc.

" The problem with nonmetallic inclusions was overcome by using better high temperature nozzles of alumina and controlling the pouring temperature more closely. As for the troubles with particles of foreign powder, engineers solved them by using a separate set of screens, filters, ducts and gaskets reserved exclusively for manufacturing NM-100 powder, and by carefully cleaning the collection chamber and all other permanent equipment which the powder contacts.

" With the institution of these controls, producers can manufacture powder so clean that NM-100 bar stock extruded from it has cleanliness comparable to that of material melted in consumable electrode vacuum furnaces. Present cleanliness requirements for the alloy (evaluated in accordance with ASTM Specification E45-63, Method A) call for material to be free from inclusions with a severity greater than three. To evaluate lots of powder for the presence of metallic and nonmetallic inclusions, processors extrude a small representative sample into bar stock."

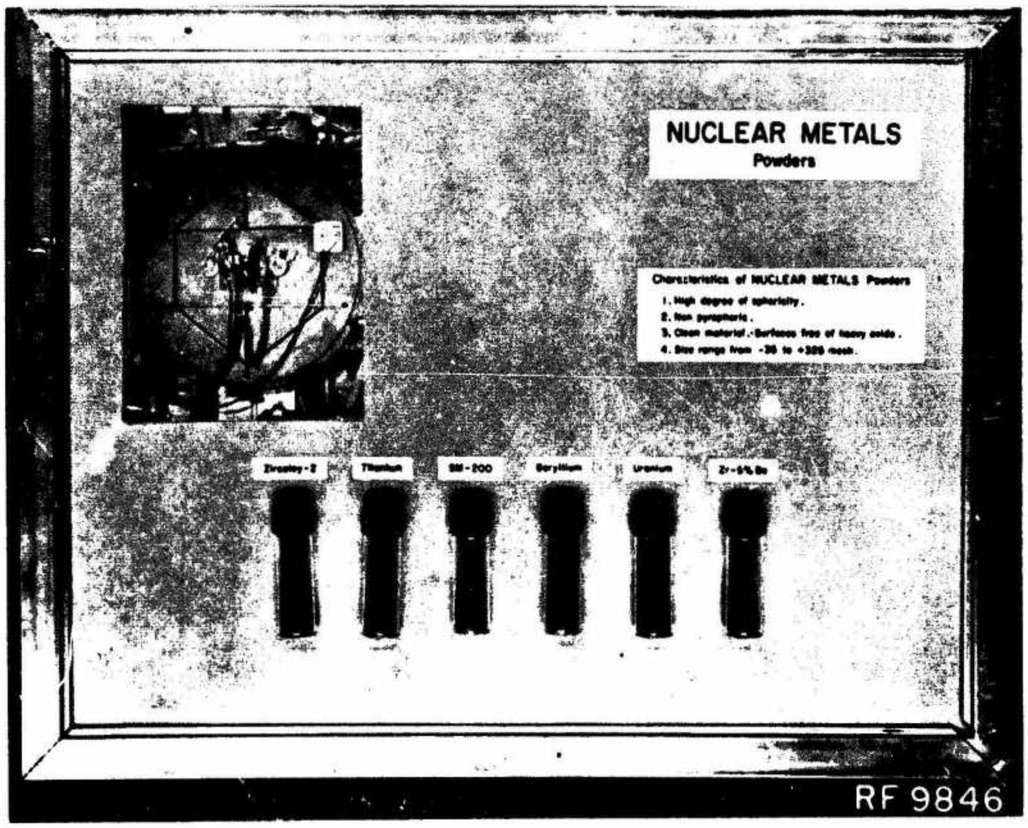

Figure #6

A new means of converting solid metal and alloys with emphasis on superalloys, reactive and refractory metals, makes use of the rotating electrode to produce spherical powder in sizes from -35 to +325 mesh with purity equivalent to the starting material. In the upper left hand corner is an exterior view of the chamber.

Courtesy of Nuclear Metals Division of Textron, Inc.

Nuclear Metals Inc. uses a unique method, which they developed for atomizing refractory and pre-alloyed powders. It is known as the Rotating Electrode Method. This technique utilizes a rotating cylinder (the electrode) made of the metal or alloy to be atomized. When an arc is struck at one end of the cylinder small spherical particles are ejected and solidify in flight. The operation is carried out in a high purity atmosphere. The powders produced by this technique are spherical and are of the same chemical composition as the rotating electrode (cylinder). (Figure #6). The Rotating Electrode Technique for atomizing metal powders is relatively costly; consequently, only very unique powders are produced by this technique. Powder produced by the atomizing process is referred to as atomized metal powder.

(b) Pulverization or Comminution is usually done by crushing, machining, grinding, or a combination of the above methods for the production of metal powders. This method, under

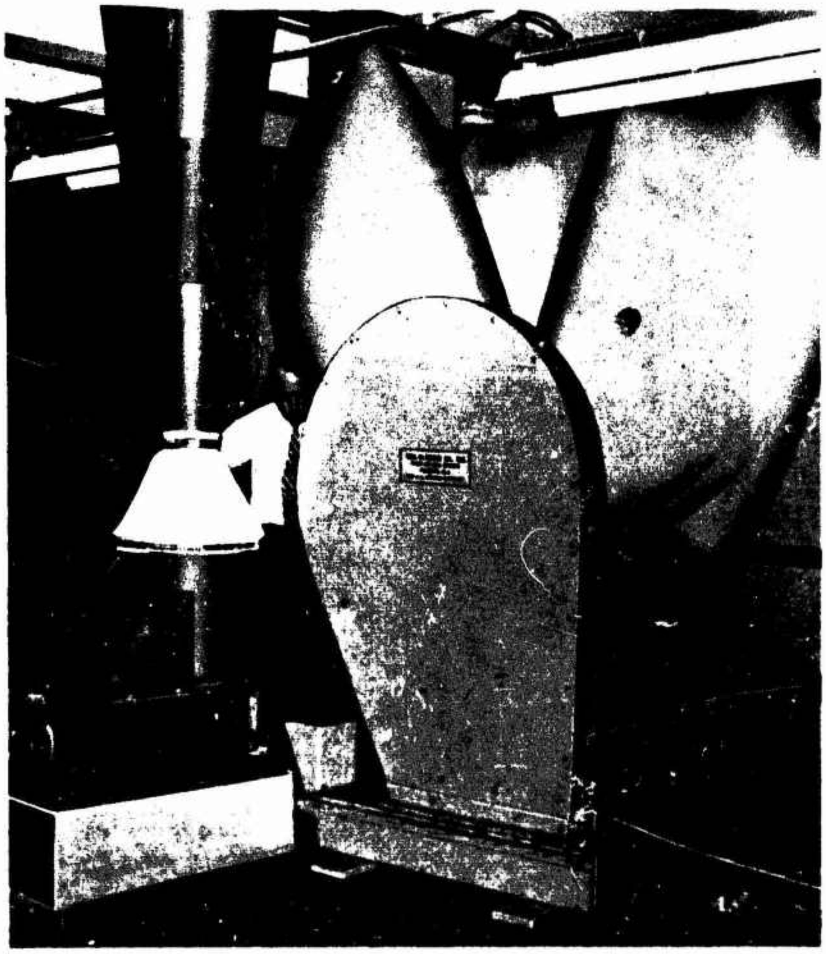

Figure #7
Courtesy of Helme Products, Inc.

"Gem Fluid Energy Mills are used to pulverize hard brittle, abrasive, soft and agglomerate materials. The simplicity of design of this unit provides controlled adaptability to a variety of process conditions. Gem Mills will dry grind to low or sub-micron particle size. Materials can be ground to an average particle size of 2 to 4 microns or finer. In simplicity and ability to control particle size, Gem Mills are years ahead. The advanced design of these fluid energy machines provides controlled fine particle grinding in the average range of ½ to 44 microns. They operate under an exclusive patent of opposing jets with classification. Though normally employing compressed air, Gem Mills may be operated with inert gas such as argon and nitrogen, or with superheated steam. The maintenance factor is very low."[1]

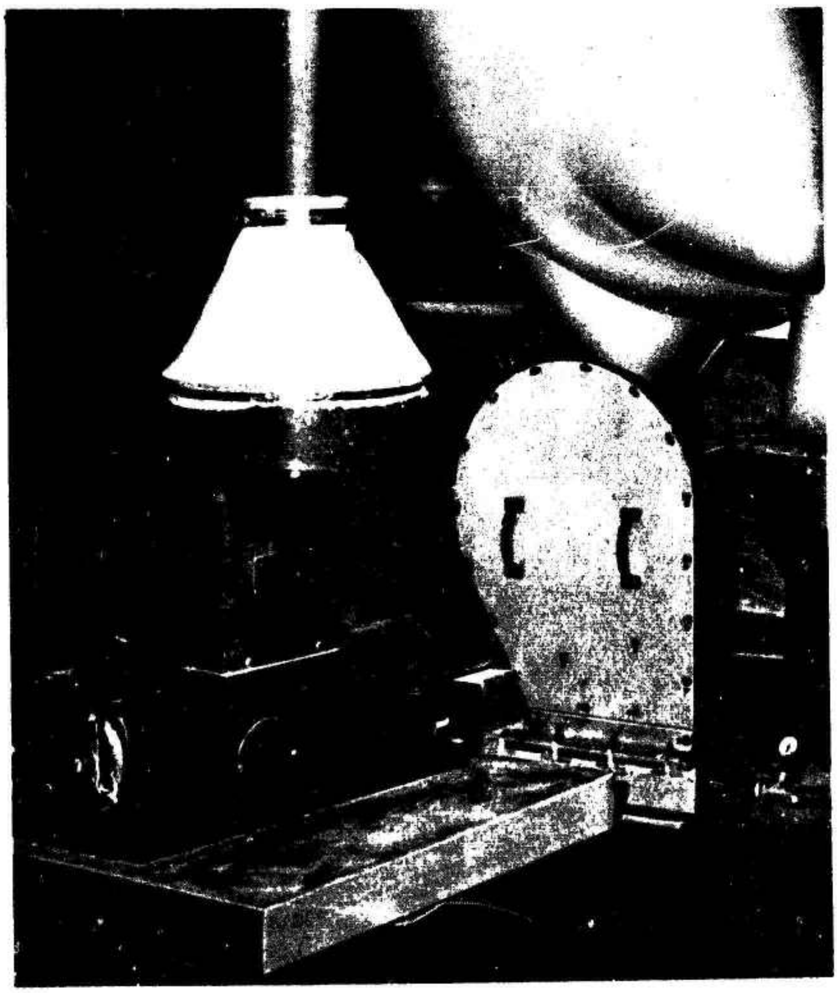

Figure #8
Courtesy of Helme Products, Inc.

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[1]Helme Products, Inc. Brochure, 9/25/63

controlled atmospheres, has also proved to be one of the most reliable processes for producing powders of such reactive metals as titanium, zirconium, and especially beryllium as well as other refractory and ferrous and non-ferrous powders. Grinding or ball milling is used to produce very fine and ultrafine powders. Figure #7 is an example of a piece of commercial equipment used to pulverize metal powder.

(2) Chemical Processes: Production methods by the chemical processes are divided into the following two categories:

(a) Reduction Process
(b) Decomposition Process

(a) The Reduction Process is the method in which a chemical compound, usually an oxide, is reduced to elemental powders. In some cases these powders are reduced from a halide or other salt solution of the basic metal. Metal powders can be produced from the following states by the reduction process:

1. Solid State
2. Gaseous State
3. Aqueous State

An example of the solid state method is the reduction of iron oxide with carbon, for the gaseous state method is the reduction of titanium from titanium vapor with molten magnesium, and for the aqueous method is the reduction of a metal from its ammonical salt solution with hydrogen under pressure.

1. Reduction processes for producing iron powders from the solid state are important methods for producing commercial grade powders. The raw materials used for producing the powders are high grade iron ore and mill scale, a key product of steel manufacture. A particular iron powder produced from the solid state reduction method is a commercial product known as sponge iron. The powder gets its name from its peculiar physical characteristics which resemble a sponge in minute (micron) size. This grade of powder is consumed in greater quantities for the fabrication of P/M parts than any other ferrous powder or powder metal for that matter. The process, in general, for producing sponge iron powders involves the heating of a mixture of high grade ferrous materials (usually in the form of oxides) mixed with crushed coke. The mixture is heated to a temperature of approximately 2000°F. Oxygen is removed from the oxide by combining with carbon in the coke to form gas compounds of carbon monoxide (CO) and carbon dioxide (CO_2) which are drawn off and the iron oxide is reduced to

form iron particles. The granules are removed from the impurities by mechanical means (magnetically) and then pulverized to desired particle size. In most cases the powder has to be further reduced and annealed in a final production step because the iron granules contain small percentages of impurities such as carbon and oxygen. The resulting sponge powders are practically pure elemental material but a very small percentage of impurities (which are not considered harmful) still remain.

Considerable amounts of copper powder are produced by the reduction of copper oxide with an exothermic gas (methane or propane) which is partially combusted. The copper oxide is reduced at low temperatures in continuous furnaces. Some refractory metals such as tungsten and molybdenum are reduced from oxides.

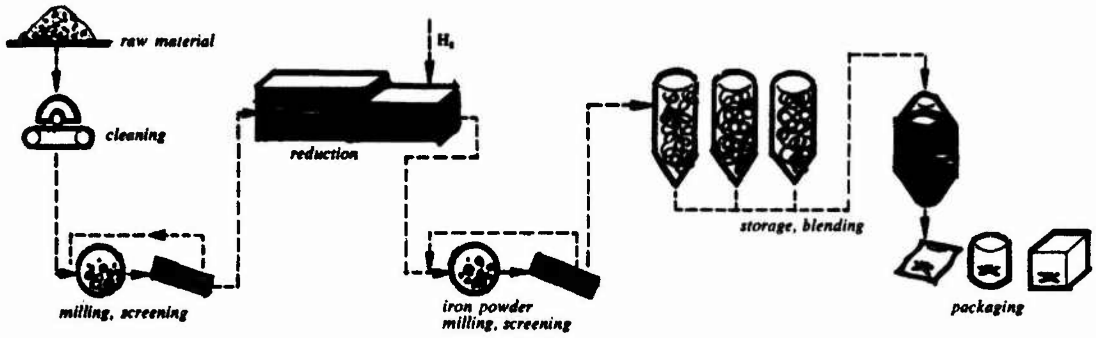


Figure #9

Courtesy of American Metal Climax, Inc., Bull. MP/65-1

Another method for reducing oxides to obtain elemental metal powders is the hydrogen reduction process. The reduction takes place in a pressure vessel in which the ore is suspended in a stream of hydrogen under pressure. The powder produced by this method has to be further reduced and ground in a mill before it is ready for compacting. A schematic diagram of the basic hydrogen reduction process is illustrated in Figure #9. Powder produced by this method is referred to as hydrogen-reduced powders.

2. An example of the gaseous reduction process is the Knoll Process in which the compound to be reduced, to obtain titanium, is a gas of $TiCl_4$. The titanium tetrachloride with magnesium in a closed container causes the titanium chloride vapor to react with liquid magnesium at a temperature of 800°c to 900°c

forming titanium metal and magnesium chloride. Whether the resulting titanium metal is in the form of a powder or a sponge depends upon the method by which the mixture reaction products are treated. The first treatment developed was leaching with dilute hydrochloric acid, in which the titanium is obtained as a coarse powder. A second and now more prevalent treatment of the reaction products of the Knoll reaction consists of vacuum sublimation. The magnesium chloride and excess magnesium is sublimed off leaving titanium sponge (Fusion metallurgy). The sponge is processed to produce titanium powders.

3. Two methods for producing metal powders by the reduction of an aqueous solution of a metal salt are worth mentioning. The first is the precipitation of copper powder from an acidified solution of copper sulfate with iron. The copper powder produced is rather impure and is not suitable for most copper powder applications. To make the powder suitable for powder metallurgy purposes further treatment is required which would increase the cost of the powder. The second method of an aqueous solution of a metal salt is the process using a reducing gas, usually hydrogen. This method is used as a commercial process for obtaining nickel powder. The mechanics of this process is quite involved, as with any reduction method from an aqueous solution, but the process does permit control of size and shape of the nickel powder to be produced.

(b) The Decomposition Process is the method by which metal powders are produced by the decomposition of chemical compounds. Two processes are worth mentioning and they are the decomposition of hydrides and the decomposition of carbonyls.

1. The decomposition of hydrides is used to produce most of the refractory metals such as titanium, tantalum, zirconium, hafnium, vanadium, columbium, thorium, and uranium. These metals are converted into hydrides by heating them in the form of sponge, chips or trimmings in hydrogen at prescribed temperatures and pressures. The hydrides produced are quite brittle and can be readily ball milled into powders of desired size. The powder hydrides are then dehydrided to obtain elemental powders.

2. The second process for the production of metal powder, usually iron and nickel, is the decomposition of their carbonyls. The carbonyls are liquids at room temperature with a low boiling point. The carbonyl vapors are formed by the reaction of the bare metal with carbon monoxide under pressure and at temperature between 200^{o}c to 250^{o}c depending upon the metallic material used. The resultant gaseous compound from iron is iron pentacarbonyl ($Fe(CO)_5$) and from nickel is nickel tetracarbonyl ($Ni(CO)_4$).

To obtain the elemental powders the vapors are decomposed by heating at atmospheric pressure. The metal precipitated out is iron or nickel depending on the gas that is decomposed. Iron particles precipitated out by decomposing $FE(CO)_5$ are quite pure but do contain some impurities of carbon and oxygen and are quite hard. By further reduction and annealing, powders are produced that are extremely pure, soft, and dense. These powders can be compacted quite readily to obtain high-dense P/M parts. Carbonyl iron powders are higher in cost as compared with sponge iron powder and their high cost prohibits their use on a competitive basis.

Nickel carbonyl powders on the other hand are produced for commercial use and can be compacted very readily. Nickel carbonyl powders are not spherical in shape as is the case with iron carbonyl powders. Powders from the process are referred to as carbonyl powders.

(3) Physical Process: The electrochemical or electrodeposition process is used to produce metal powders referred to as electrolytic powders. The name is derived from the method of processing to describe the product that is derived therefrom. The electrochemical process is probably more important for producing copper powders than any other methods. It is also used to produce iron powders. The process is similar to electroplating. Instead of plating the cathode a powdery or porous metal is deposited at the cathode.

For producing electrolytic copper powders a lead cathode for collecting the deposit is generally used. The anode, usually made of refined pure copper and a sulfate electrolyte is used to complete the processing system. The deposit on the cathode falls to the bottom of the tank or is brushed off the cathode and collects in the bottom of the tank. It is removed, filtered, washed, and finally reduced and annealed as required. This processing results in a semi-cake which must be pulverized or milled into powders of desired size (Figure #10).

For producing electrolytic iron powder a stainless steel cathode is employed and the anode is usually made of Armco iron or low carbon steel. The electrolyte used is an acid solution. The ferrous powdery deposit collected on the cathode is brittle, porous, and contains impurities of hydrogen and oxygen. The iron powders go through similar processing steps used for copper and is then reduced and annealed to obtain a soft electrolytic powder. The iron powders produced are extremely pure and possess good compressibility characteristics for compacting. Higher green and sintered

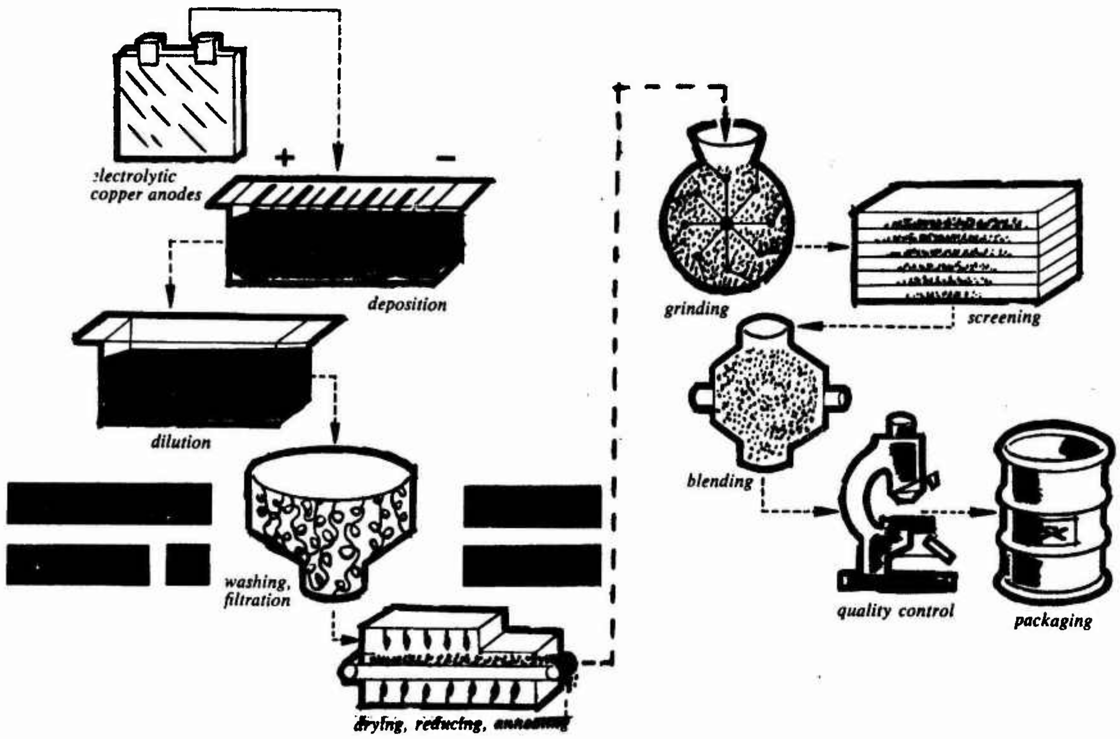


Figure #10

Courtesy of American Metal Climax, Inc., Bull. MP/65-1.

densities can be obtained from the ferrous powders made from this process. Electrolytic iron powders are higher in cost than ferrous

IRON

Material	Density gms/cc	UTS PSI	Elong. % in 1 inch	Hardness	Yield psi	Uses
Iron Low Density	6.0	15,000	2	-	12,000	-Low load bearings, low property structural.
Iron High Density	7.0	19,000	6.5	-	14,000	-Medium load bearings, average structural, may be case hardened.
Iron High Density	7.3	32,000	1.5	Rb 50	30,000	-Heavy duty bearings, structural parts. may be case hardened.
Iron High Density	7.3	38,000	15.0	Rb 30	23,500	-Ductile, machinable, structural parts.
Iron High Density	7.5	34,500	1.5	Rb 60	31,000	-Heavy duty bearings, structural parts, may be case hardened and plated.
Iron High Density	7.5	41,000	25.0	Rb 40	27,000	-Very ductile, accurate structural parts, machinable, may be case hardened and plated.
Iron - Copper	5.8-6.2	25,000	-	Rb20-50	-	-Heavy duty bearings, structural parts.
Iron - Copper	6.0-6.5	30,000	-	Rb20-50	29,000	-Gears, cams, structural parts, light shock.
Iron - Copper	6.5-7.0	37,000	Nil	Rb40-60	-	-Gears, cams, structural parts, no ductility.
Iron	6.2	17,000	2.0	Rb 40	-	-Electro magnetic, some structural parts.
Iron - Copper	7.4	60,000	1.0	Rb 55	55,000	-Tough machinable, gears, structural parts, cannot be case hardened.
Iron - Carbon Copper	7.4	135,000	.5	Rc 35	-	-Very tough, heavy duty gears, structural parts, can be plated.
Iron - Carbon	6.0-6.4	30,000	Nil	Rb 40	-	-Gears and structural parts, cannot be plated.
Iron - Carbon	6.5-7.0	45,000	Nil	Rб 60	-	-Gears and structural parts, cannot be plated.
Steel	7.3	150,000	1.0	Rc 35	-	-Excellent strength, good ductility structural parts.

Figure #11

Courtesy of Sintered Products Division, Russell, Burdsall & Ward Bolt and Nut Co.

powders produced by the reduction process and consequently is not used as widely or is as popular as sponge iron for the fabrication of P/M parts. The powder is reported to be an excellent choice for very high dense ferrous structural parts (Figure #11).

c. Powder Testing: Powder testing is required to ensure good results in the production of metal powders. A sample is taken from a lot or several samples are taken to test the lot. Testing of elemental powders is done before blending. Testing is done both by the powder producer and the powder consumer. It is easier for the powder producer to sample his lot for testing but it is a bit more difficult for the consumer to take representative samples because the powder has been canned into drums. Devices are available for sampling different layers of powders in a drum. These devices are called thieves and they are not easy to work with. Testing is required so that both the processing and quality of the powder products are controlled. It is important that the various physical and chemical properties of the raw powders are measured and determined. The P/M parts producer would be at a disadvantage if necessary parameters are not established to reproduce identical properties for second orders. These parameters are important to the P/M parts producer in order for him to duplicate physical and mechanical properties which have already been determined and established for processing the original P/M shapes required by the customer.

Elemental powder testing may be divided into the following categories:

(1) Chemical Test
(2) Physical Test
(3) Simulated Behavior Test

Chemical testing of metal powders are used to establish evidence of impurities or alloying ingredients. Microscopic tests are

Representative Properties

CHEMICAL ANALYSIS		
	Normal Range (%)	Specifications (%)
Total Iron	97.0-98.25	96.0 Min.
Carbon	0.015-0.022	0.030 Max.
Sulfur	0.005	
Phosphorus	0.012	
Manganese	0.30-0.60	
Acid Insoluble	0.20-0.45	0.50 Max.
Hydrogen Loss	0.70-1.30	1.50 Max.

Figure #12

Courtesy of American Metal Climax, Inc., Bull. MP/65-1.

employed for determining the nature and form of the powder's metallurgical characteristics but analytical methods are necessary to establish basic parameters and variables for specification purposes (Figure #12).

(1) Chemical Tests: The usual methods for analyzing metals are employed for the chemical analysis of metal powder. The specific chemical tests for metal powders are:

(a) Hydrogen Loss Test
(b) Insoluable Matter Test

(a) Hydrogen Loss Test: The test is used to determine the loss in weight of metal powder when a representative sample is heated for a specified time and temperature in an atmosphere of hydrogen: basically, the test is a measure of the oxygen

Representative Properties of Pyron 100 and D-63 Iron Powders

Pyron 100 and D-63 differ chemically and physically in only two significant respects: chemically, in oxygen content as indicated by hydrogen loss, and physically, in screen analysis.

	CHEMICAL			
	Normal Range (%)		Specifications (%)	
Total Iron	97.5-98.5		96.0 Min	
Carbon	0.015-0.022		0.20 Max	
Sulfur	0.005			
Phosphorus	0.012			
Manganese	0.45-0.65			
Acid Insoluble	0.20-0.45		0.50 Max	
Hydrogen Loss	Pyron 100: 0.70-1.20	D-63: 0.3-0.5	Pyron 100: 1.40 Max	D-63: 0.6 Max

PHYSICAL		
	Normal Range	
Powder Flow-Hall	27-34 sec	
App. Density	2.20-2.50 g/cc	
Screen Analysis (%)		
	Pyron 100:	D-63:
−80+100 Mesh	1% Max	3% Max
−100+150	9-14	9-14
−150+200	19-23	25-35
−200+250	6-9	10-15
−250+325	20-28	20-28
−325	28-42	20-30

Figure #13

Courtesy of American Metal Climax, Inc., Bull. MP/65-1.

content of the sample (Figure #13). The oxide in the powder is reduced by hydrogen; consequently, the powder will weigh less. The procedure for the test is covered in Metal Powder Industries Federation Specification No. 2-48.

(b) Insoluable Matter Test: This test is used to determine the amount of insoluable impurities in the metal powder which has been introduced into the powder during production. The procedure for this test is covered in Metal Powder Industries Federation Specification No. 6-54. Another specification for determining the iron content of ferrous powders is MPIF Specification No. 7-54.

(2) Physical Test: The tests for determining physical properties and powder characteristics are divided into the following categories: (Figure #14)

(a) Apparent Density
(b) Flow Rate
(c) Particle Size and Distribution

PHYSICAL ANALYSIS

	Low Density 100 Mesh	Special Low Density 100 Mesh	Special Low Density 20 Mesh
Powder Flow-Hall	35 Sec. to Poor	35 Sec. to Poor	35 Sec. to Poor
Apparent Density (g/cc)	1.4-1.8	1.00-1.40	1.00-1.40
Screen Analysis (%)			
−80+100 Mesh	2.0 Max.	2.0 Max.	18-35
−325	20-35	10-30	5-20

Figure #14
Courtesy of American Metal Climax, Inc.
Bull. MP/65-1

(a) Apparent Density is the weight of a unit volume of powders (before pressing) determined by a specified method and is expressed in grams per cubic centimeter. The details for measuring apparent density are described in ASTM Specifications B212 and B213.

(b) Flow Rate is generally expressed in seconds. It is determined by measuring the amount of time required for a 50-gram sample of powder to flow through the orifice of a standard Hall Flow Meter. The details for conducting the test are given in MPIF Specification No. 3-45. Flow characteristics determine the ease with which metal powders can be fed into a die. Poor flow rates not only cause slow and uneconomical feeding but it also makes uniform filling of the dies difficult. Poor flow characteristics are also detrimental to good compaction in the dies.

(c) Powder Size and Size Distribution are very important in respect to flow rate and die filling. Powder size and size distribution are also important in respect to the behavior of the powder during processing, such as shrinkage in sintering, etc., and also effects the properties of the finished P/M parts. Particle size is not a concise quantity but for any given nonspherical particles several values with different meanings are used, depending on the sizing method used.

SIEVE SERIES

Meshes per Linear Inch	U. S. Sieve No.	Opening In Inches	Opening in Millimeters Micron=.001 mm	Wire Diameter in Inches	Wire Diameter in Millimeters
27.62	30	.0232	.590	.0130	.330
32.15	35	.0197	.500	.0114	.290
38.02	40	.0165	.420	.0098	.250
44.44	45	.0138	.350	.0087	.220
52.36	50	.0117	.297	.0074	.188
61.93	60	.0098	.250	.0064	.162
72.46	70	.0083	.210	.0055	.140
85.47	80	.0070	.177	.0047	.119
101.01	100	.0059	.149	.0040	.102
120.48	120	.0049	.125	.0034	.086
142.86	140	.0041	.105	.0029	.074
166.67	170	.0035	.088	.0025	.063
200.00	200	.0029	.074	.0021	.053
238.10	230	.0024	.062	.0018	.046
270.26	270	.0021	.053	.0016	.041
323.00	325	.0017	.044	.0014	.036

Figure #15
Courtesy of The Joseph Dixon Crucible Company

The sieve method is the standard technique used for sizing powders and is conducted according to ASTM Specification B214 and MPIF No. 5-62 (Figure #15). This method is actually a screen test. The powder particle size and size distribution is determined by conventional screen methods. A sample lot of powder is passed through successive sieves (standard sieve sizes) and the amount of powder passing through the sieves can be determined. For most applications the test is sufficient to determine the size distribution of coarse and medium fine grades. The method is used by most powder producers although other methods for classifying powder are employed.

Screen, Sub-screen and Submicroscopic Measurements

TABLE of EQUIVALENT LINEAR MEASUREMENTS

UNIT	in.	mm	μ	mμ	Å	μμ	x-u
1 in. (inch)	1	25.4	25400	2.54×10^{7}	2.54×10^{8}	2.54×10^{10}	2.54×10^{11}
1 mm (millimeter)	.0394	1	1000	10^{6}	10^{7}	10^{9}	10^{10}
1 μ (micron)	3.94×10^{-5}	10^{-3}	1	1000	10,000	10^{6}	10^{7}
1 mμ (millimicron)	3.94×10^{-8}	10^{-4}	10^{-3}	1	10	1000	10,000
1 Å (angstrom unit)	3.94×10^{-9}	10^{-7}	10^{-4}	0.1	1	100	1000
1 μμ (micromicron)	3.94×10^{-11}	10^{-9}	10^{-6}	10^{-3}	0.01	1	10
1 x-u (siegbahn unit)	3.94×10^{-12}	10^{-10}	10^{-7}	10^{-4}	10^{-3}	0.1	1

Table of Relative Sizes

Material	Approximate Size Limit	In Å Units
Proton	2×10^{-6} μμ	0.00000002
Electron	38×10^{-4} μμ	0.000038
Cosmic Ray	5×10^{-2} μμ	0.0005
Shortest X-Rays	6 μμ	0.06
Diameter of Hydrogen Atom	1.08 A	1.08
Longest X-Rays	8 mμ	80
Lower Limit of the Microscope	100 mμ	1,000
Wave Length of Violet Light	400 mμ	4,000
Wave Length of Red Light	650 mμ	6,500
Bacteria (cocci)	2 μ	20,000
Red Blood Cells	8 μ	80,000
White Blood Cells	25 μ	250,000
Lower Limit of Visibility (naked eye)	40 μ	400,000
325 Mesh opening	44 μ	440,000
Diameter of Human Hair	50 μ	500,000
100 Mesh opening	149 μ	1,490,000

Figure #16
Courtesy of The Joseph Dixon Crucible Company

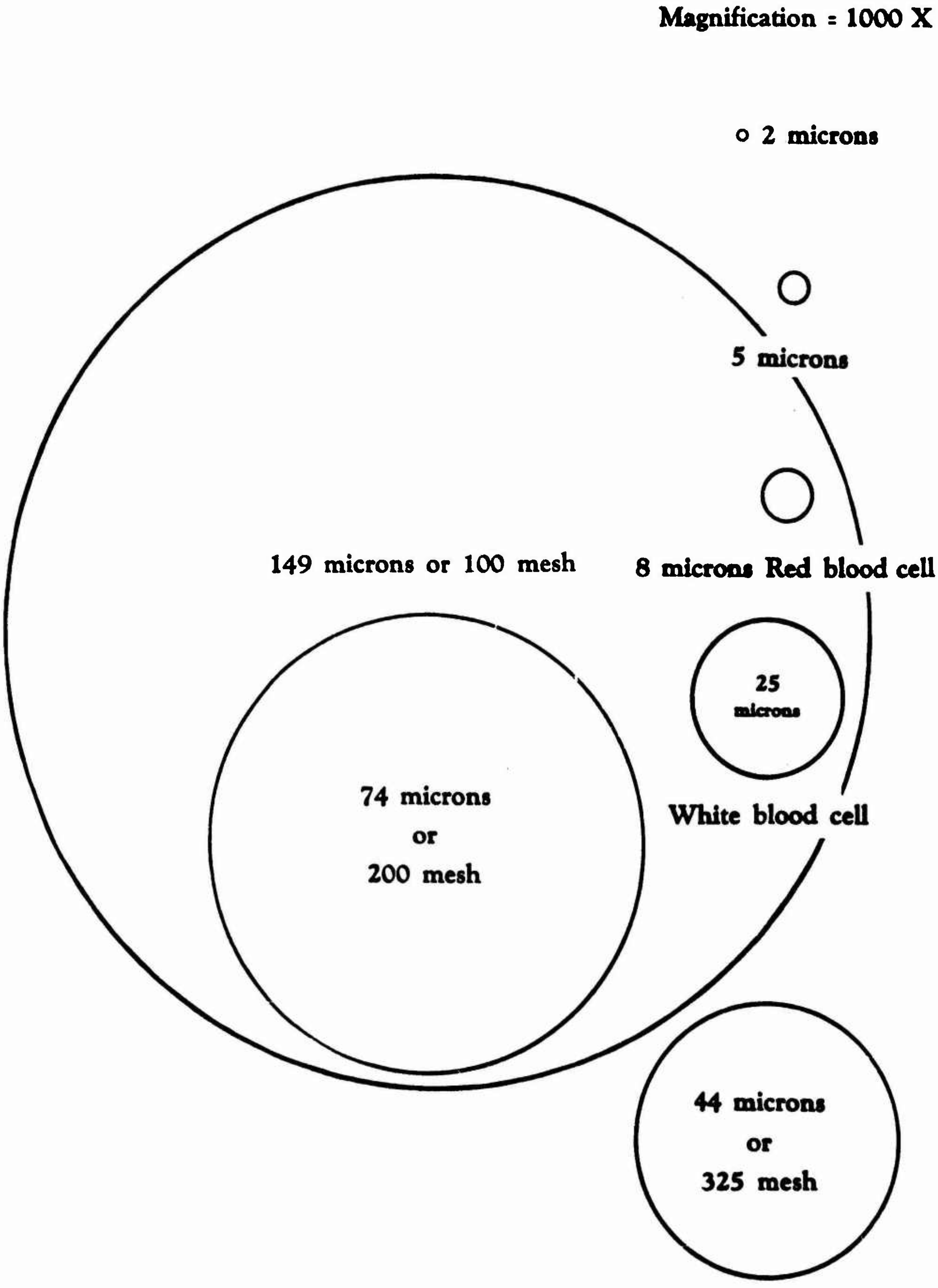


Figure # 17
Courtesy of The Joseph Dixon Crucible Company

Dry sieving is the general practice for determining particle sizes and in this method the powder is agitated as it passes through a series of screens (sieves). A widely used method is the screening of 100 grams of powder for 15 minutes in a standard agitating machine (Figure #16). The Tyler Ro-Tap Automatic sieve

The following are approximate theoretical meshes with millimeter and micron equivlents.

625	.020 or 20 microns
1250	.010 or 10 microns
2500	.005 or 5 microns
5000	.0025 or 2½ microns
12500	.001 or 1 micron

This table was first prepared about 1940 by Mr. Sherwood B. Seely of the Joseph Dixon Crucible Co. for use in comparing grapnite particles. Because of the practical presentation we believe you might like this copy for your files.

Figure #18
Courtesy of The Joseph Dixon Crucible Company

shaker is usually employed. The details for utilizing this procedure are covered in MPIF Specification No. 5-62 and a standard set of sieves specified by ASTM or equivalent Tyler Standard Screen Scale sieves are used.

The newest method that is now available for determining the particle size distribution of metal powder is the Coulter Counter (Figure #20). The number of particles in a suspension flowing through a small aperture of the counter having an immersed electrode on either side are counted. The particle concentration is such that the particles traverse the aperture one by one. The particles traversing the aperture momentarily change the resistance between the electrode and produce a voltage pulse which is proportional to the particle volume; then the particles are counted. Suitable controls are provided so that particles above a minimum size are counted.

The Model B and Model M combination provides 16 choices of data presentation

Choice of Data quantities		Choice of Data Forms		Basic Volumetric Measurement expressed as:
A. Concentration quantities B. Relative quantities	BY	A. Cumulative counts B. Differential counts C. Cumulative volume D. Differential volume	VS	A. Equivalent spherical diameters (in microns) B. Volume (in cubic microns)

Differential Count	Cumulative Count	Relative Differential Volume	Relative Cumulative Volume		Equivalent Spherical Diameter in microns	Cubic Microns
1	1	4	4		95.0	450×10^3
3	4	6	10		75.2	225×10^3
15	19	15	25		60.0	112.5×10^3
54	73	27	52		47.5	56,250
160	233	40	92		37.8	28,125
380	613	48	140		30.0	14,062
732	1345	48	188	VERSUS	23.7	7,031
1160	2505	36	222		18.8	3,515
1612	4117	25	247		15.0	1,757
1281	5398	10	257		11.8	878
773	6171	3	260		9.4	439
418	6589	1	261		7.5	219
192	6781	1	262		5.9	109

There are over 4 000 Coulter Counter installations for size distribution analysis for such materials as

Coulter Electronics engineering has developed recent patents issued and pending throughout the world to improve on the original patented basic Coulter principle allowing independence of electrolyte conductivity and simplified data handling.

The patented principle determines the number and size ot particles suspended in an electrically conductive liquid. The suspension flows through e small aperture having an immersed electrode on either side. Concentration is such that the particles traverse the aperture substantially one at e time. Each particle passage displaces elecrolyte within the aperture, momenterily changing resistance between electrodes and producing e voltage pulse ot e magnitude proportional to particle volume. The resultant series of pulses is electronically amplitied, scaled and counted. Voltage pulses ere displayed on the oscilloscope screen as e pattern of vertical "spikes". The pulse pattern serves es e guide for measurement and as e monitor ot instrument performance. Pulses ere elso ted to dual threshold circuits having adjustable screen-out voltage levels. Pulses exceeding, or talling between, these levels are counted.

The electrolyte in the aperture torms the principal resistance between the electrodes. The resistance change due to particle passage is:

$$\Delta R = \frac{\rho v}{A^2} \cdot \frac{1}{\frac{1}{1-\rho/\rho'} - \frac{a}{xA}}$$

ρ = electrolyte resistivity

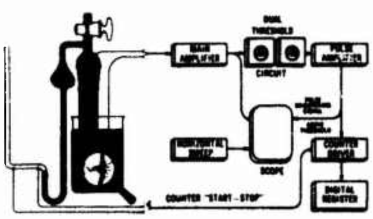
A = aperture area normel to axis

v, ρ', a = particle volume, effective resistivity, and area normal to aperture axis

x = particle dimension ratio, l/d = $\frac{\text{length parallel to aperture axis}}{\text{diameter of equivalent sphere}}$

Thus, for e given aperture size and electrolyte, response is primarily proportional to particle volume.

Operation When the stopcock is opened, a controlled external vacuum initiates flow from the beaker through the aperture, and unbalances the mercury manometer. Closing the stopcock then isolates the system from the external vacuum, and the siphoning action of the rebalancing manometer continues the sample flow. The advancing mercury column activates the counter via start and stop probes, providing a count of the relative number of particles in a fixed volume of suspension (e.g., 0.5 ml or 2 ml). Counts for each size range are sequentially collected. Thus cumulative or frequency count data may be plotted from the readout.



Depending on the nature of the sample, measurement factors generally fall into the following ranges:

Aperture size, 2 to 3 or more times the diameter of the largest particles in the sample (sizes, 30, 50, 70, 100, 140, 200, 280, 400, 560, 1000 and 2000 microns).

Beaker volume, 5 to 400 ml to suit quantity needed for analysis.

Particle concentration, 1,000,000 to 1,000 per ml and lower (.0001 to 1 mg per ml, varying with size range and density of particles).

Electrolyte resistivity, 10 to 1,000 ohm-cm (1% salt water at about 55 ohm-cm is frequently used).

4% NH_4CNS in isopropanol is a common non-aqueous electrolyte.

Agitation during measurement, as required to maintain uniform suspension.

Dispersing agents, as required.

Figure #19

Courtesy of Coulter Electronics, Inc., Bull. B-1

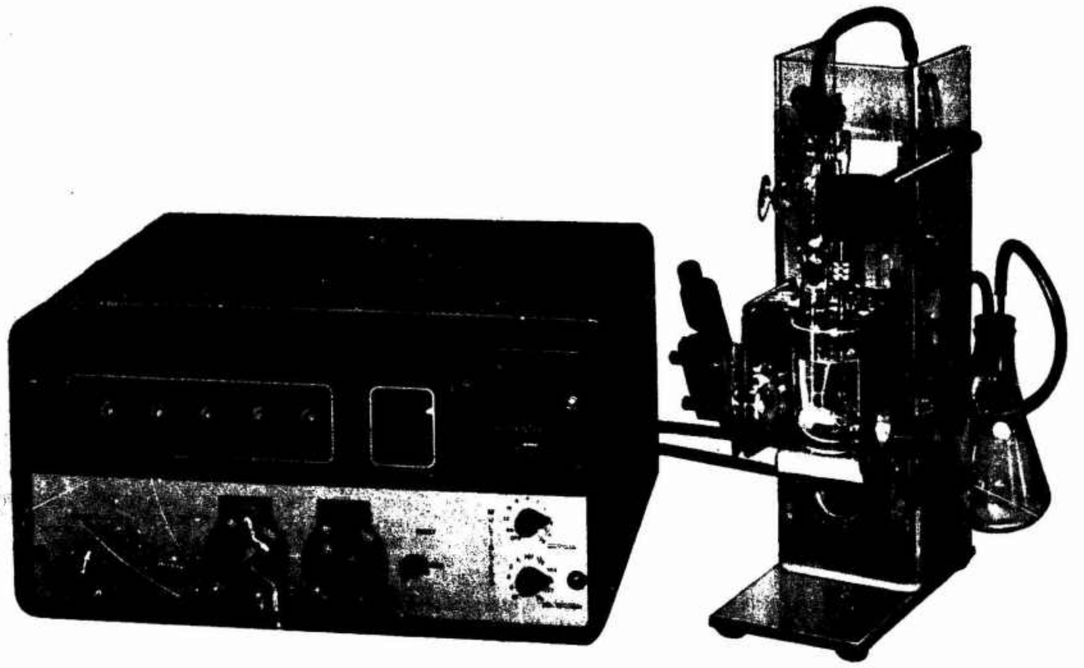
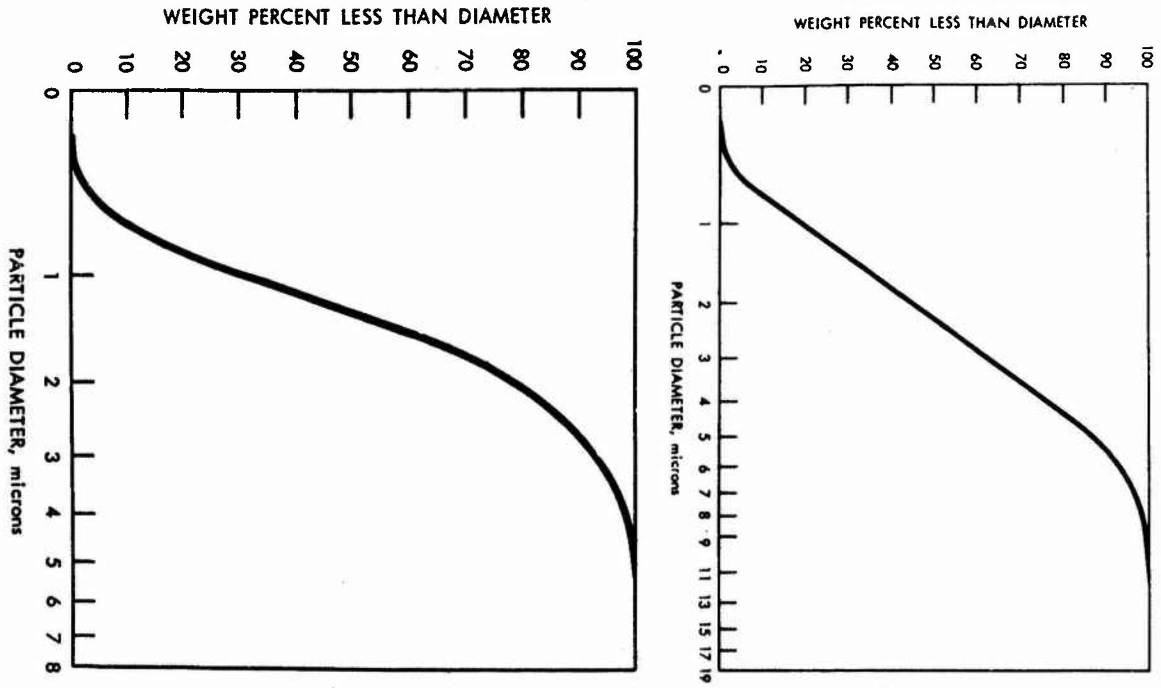


Figure #20

Courtesy of Coulter Electronics, Inc., Bull. B-1

The microscoping sizing technique is employed for classifying metal powders having sizes of one to a few microns. This method has limitations as other methods of sizing and also has the disadvantage of being quite tedious but the microscope is a versatile tool for examining the size, shape, purity and structure of metal powders.

Another technique for determining particle size distribution is the micromerograph method. Metal powders are suspended in air with a burst of nitrogen through a device which breaks up the agglomeration of the sample. The device consists of a conical annulus. The suspended particles settle in a column approximately 8 feet high. An automatic balance is located at the bottom of the column where the sediments are collected in a pan and weighed. A recorder records the cumulative weight of the settled powders as a function of time. Using Stokes' Law the particle size distribution is determined (figures #21a and #21b). The micromerograph method determines size of particles from one to one hundred microns. The method is nonfractionating. The instrument is quite costly and is a drawback to the utilization of the method.



(a)
Tungsten Powder Particle Size Distribution

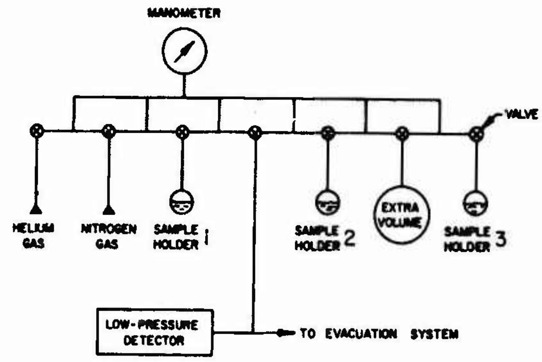
(b)
Molybdenum Powder Particle Size Distribution

Figure # 21

Reprinted by special permission from Journal of Metals, AIMF, from the article "Preparation of Refractory Metal Powders with Unusual Properties" by S.H.Smiley, D.C.Brater, & H.L.Kaufman, as published in the June 1965 issue of the JOURNAL OF METALS, (C) 1965.

The Roller Air Analizer method is used to classify powders of subsieve and fine particle size usually in the range of 5 to 40 microns. The details for utilizing the technique are described in ASTM Specification No. B293. This apparatus works on the principle of Stokes' Law as applied to the fall of particles through a rising gas stream. The metal powder is suspended in a stream of air flowing at a certain rate through a cylindrical settling chamber. The cross-sectional area of the chamber in square centimeters determine the velocity of the air stream in cm/min for a given rate of flow of air for a given time. This velocity determines (by Stokes' Law) the maximum size of particle which is carried through the chamber without settling. By using settling chambers of different diameters, a powder may be classified into a series of sizes. This is done by converting the numerical values obtained from the analizer and substituting into Stokes' Law.

Other methods for determining particle size and particle distribution are used but the details will not be discussed. For the interested reader they are:



SYSTEM SCHEMATIC
Figure 1

PRINCIPLE OF SURFACE AREA AND PORE VOLUME DETERMINATION

The surface area of particle matter is measured by determining the quantity of gas necessary to form a single layer of gas molecules, i.e., a monolayer on the surface of the material being examined. This is accomplished using nitrogen, or other suitable gases at the temperature of liquid nitrogen, approximately minus 195°K, because under these conditions the gas molecules form a uniform, tightly packed layer. Moreover, under this condition, the space occupied by each gas molecule is known within reasonable limits.

The gas adsorption technique is based on the well known theoretical principles of Brunauer, Emmett and Teller [1, 2] and discussed by Orr [3] and others.

Pore volume is established by an analysis of the conditions under which pores — void spaces due to microscopic cracks and crevices within solids — fill with adsorbed gases and are then freed of the gases. Once the adsorbing gas has formed a monomolecular layer, nitrogen or krypton is added further to the system until the saturation pressure of liquid nitrogen is attained, this filling the pores with condensed gas. The adsorbed gas is then removed step-by-step until the adsorbed gas is reduced again to the monolayer volume.

Barrett, et al [4] and Pierce [5] have discussed pore volume theory in some detail.

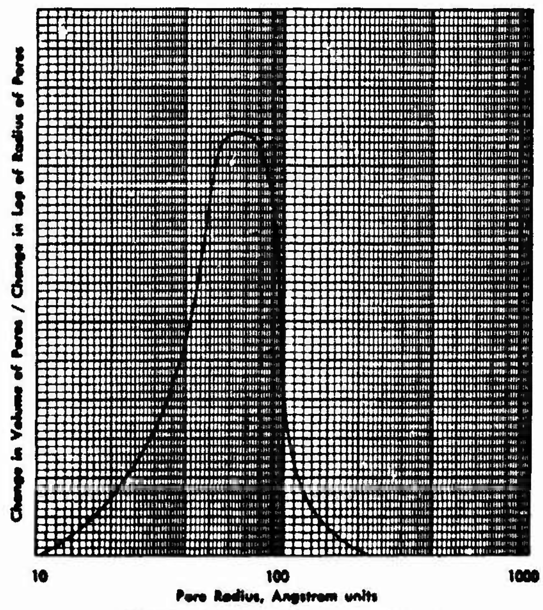
ANALYSIS PROCEDURES

Surface Area

Surface area measurements involve (1) selecting and weighing the powder sample, (2) heating it under vacuum to remove the contaminating gases and vapors which the sample inevitably carries with it after exposure to the atmosphere, (3) establishing the volume of the sample (unless the material's absolute density is known with sufficient accuracy for its volume reliably to be calculated), (4) readsorbing nitrogen gas in measurable increments, and (5) computing the results.

Pore Volume

Determining the volume distribution of pores in a powder requires steps 1, 2 and 3 described above and continuation of step 4 until the nitrogen saturation pressure is reached (approx. 760 mm mercury). As step 5, the nitrogen gas is then desorbed in measurable increments until the sample is essentially free of gas again, and (6) computing the results. A typical pore volume distribution curve is shown in Figure 2.



TYPICAL PORE SIZE DISTRIBUTION
Figure 2

Figure #22
Courtesy of NUMEC Instruments and Controls Corporation

AMAX

electrolytic copper powder specifications

The following table covers standard types of AMAX Electrolytic Copper Powders. Information on the production of powders to meet other specifications is available on request.

	Chemical Analysis (%)					Screen Analysis (%) Mesh Size					
AMAX Type	Metallic Cu	H_2 Loss	HNO_3 In Sol	Apparent Density (gm/cc)	Flow (sec/50 gm)	100 +	100 − 150 +	150 − 200 +	200 − 250 +	250 − 325 +	325 −
A	99.5 Min	.30 Max	.03 Max	2.4-2.6	32 Max	.5 Max	5-15	25-35	6-13	19-29	22-32
LB	99.5 Min	.30 Max	.03 Max	2.45-2.55	33 Max	.2 Max	3-13	17-27	5-12	18-28	33-43
B	99.5 Min	.30 Max	.03 Max	2.5-2.6	32 Max	.2 Max	1-11	13-23	3-10	17-27	43-53
HB	99.5 Min	.30 Max	.03 Max	2.75-2.85	30 Max	.2 Max	1-11	14-24	5-12	15-25	42-52
LC	99.0 Min	.75 Max	.03 Max	1.5-1.75	(Scott)	.1 Max	.5 Max	4.0 Max	1.5 Max	2-7	90 Min
MC	99.0 Min	.60 Max	.03 Max	1.9-2.1	(Scott)	.1 Max	.5 Max	5 Max	5 Max	15 Max	80 Min
C	99.0 Min	.75 Max	.03 Max	2.1-2.5	(Scott)	.1 Max	.5 Max	4.0 Max	1.5 Max	2-7	90 Min
M	99.25 Min	.50 Max	.03 Max	2.5-2.6	40 Max	.2 Max	1-6	5-15	1-6	10-20	65-75
HM	99.25 Min	.50 Max	.03 Max	2.6-2.7	35 Max	.2 Max	1-6	5-15	1-6	10-20	60-70
LU	99.4 Min	.40 Max	.03 Max	2.3-2.4	35 Max	.2 Max	1-10	9-19	3-9	16-26	50-60
U	99.4 Min	.40 Max	.03 Max	2.5-2.6	35 Max	.2 Max	1-10	9-19	2-9	12-22	55-65
HU	99.4 Min	.40 Max	.03 Max	2.7-2.8	32 Max	.2 Max	1-10	7-17	2-9	13-23	54-64
AJL	99.25 Min	.30 MPA	.03 Max	3.5-4.0	24 Max	.8 Max	7-17	17-27	3-10	15-25	35-45
O	99.5 Min	.20 Max	.03 Max	4.0-5.0	24 Max	60-75	20-35	25 Max	—	—	5.0 Max
Coarse Powders*	99.5 Min	.30 Max	.02 Max	2.25-3.8	40 Max	+20 .2 Max	−20 +200 65—90		−200 +325 5—20		−325 5-15 Max

**A number of Coarse Powders within this broad specification are available. Other Standard or Special Copper Powders are available or can be produced to customers requirements.*

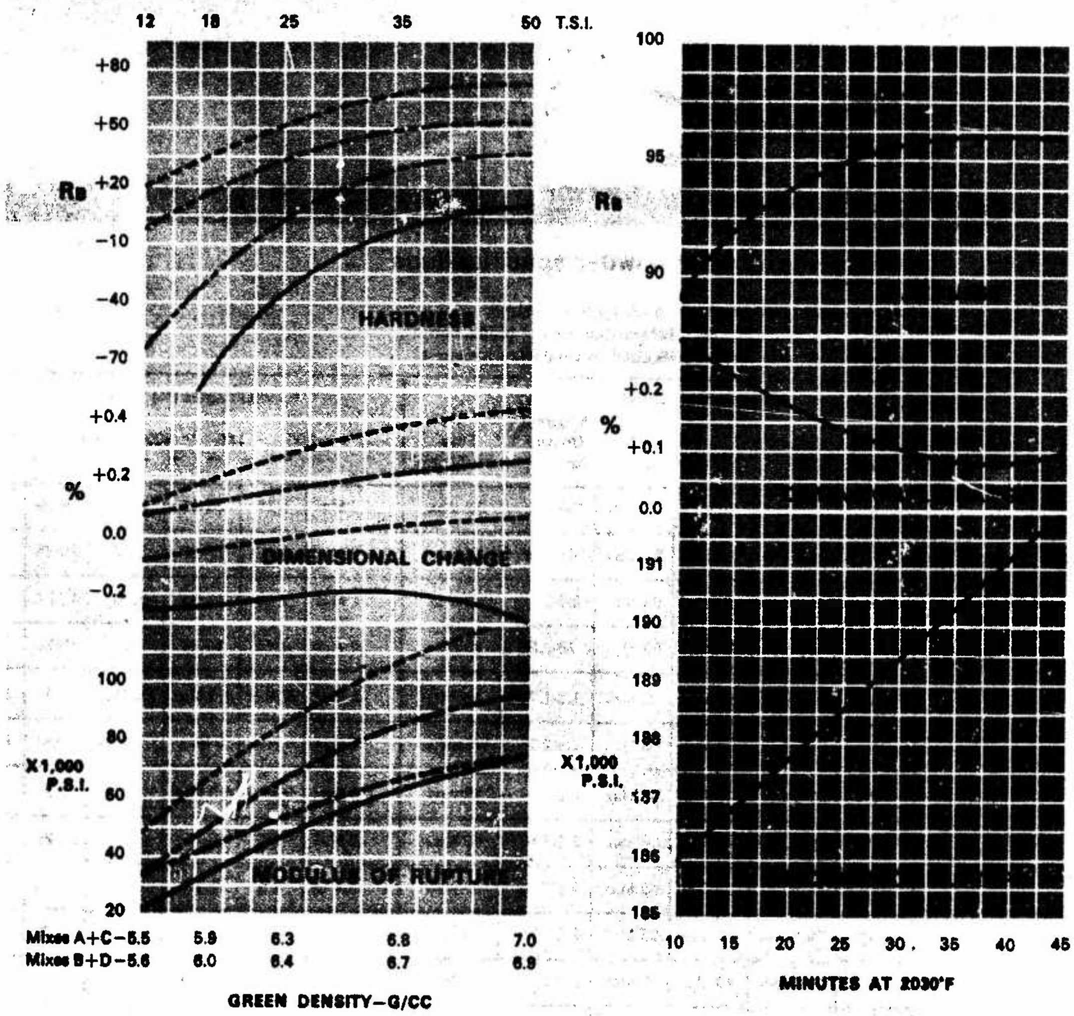
Figure #23
Courtesy of American Metal Climax, Inc.
Bull. MP/65-1

Sponge Iron Powder MP32

An Iron Powder with excellent compressibility and green strength

A low growth, high strength base material for infiltrated parts

Briquetting pressure | **Infiltrated**



Composition (Plus % parts ZN Stearate)

MIX A ———— 100 Parts MP32

MIX B — — — — 99 Parts MP32
1 Part Carbon

MIX C — — — — — 98 Parts MP32
2 Parts Copper

MIX D — — — — — — 92 Parts MP32
7 Parts Copper
1 Part Carbon

Sintering 20 minutes at 2030°F
Atmosphere Endothermic
Dew point +30°F

In an Endothermic atmosphere—Dew point +25°F

Mix details	Briquettes
Iron skeleton: 99 Parts MP32, 1 Part Carbon, 1 Part ZN Stearate	All bars pressed at 28 T.S.I. Green Density 6.25 G/CC
Infiltrant: Copper/Manganese/Iron Alloy (16.5% by weight)	Sintered and Infiltrated Density 7.3 G/CC

Sintering and Infiltrating
All bars sintered and infiltrated in one furnace pass.
For time at temperature see graph.

Figure #24
Courtesy of DOMTAR CHEMICALS LTD.
Metal Powders Division

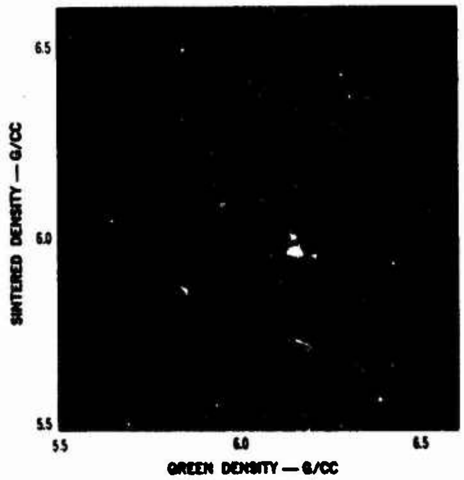
PROPERTIES OF PYRON 100 IN COMBINATION WITH COPPER AND/OR CARBON

For the development of this data, representative standard samples of Pyron 100 Iron Powder and AMAX Type U Electrolytic Copper Powder were used:

SPECIFICATIONS		
PROPERTY	Pyron 100 Iron Powder	AMAX Type U Electrolytic Copper
Apparent density (g/cc)	2.3-2.5	2.5-2.6
Flow (sec)	27-34	35 max
H_2 loss (%)	0.70-1.20	0.40 max
Insolubles (%)	0.50 max	0.03 max
Screen analysis (%) +100 mesh −325 mesh	 1.0 max 28-42	 0.2 max 55-65

GRAPH NO. 8

Sintered Density vs Green Density Pyron 100/Copper



Test Conditions:
Sintering temp 2050F
Sintering time 45 min
Atmosphere H_2

Figure #25
Courtesy of American Metal Climax, Inc.
Pub. MP/65-2

1. Andreasen Pipette Method
2. Sedimentation Balance Method (based on Stokes' Law also)

A test used to determine the physical characteristics of a powder is the specific surface test. Three methods for determining the overall specific surface of a powder are:

1. Fisher Subsieve Sizes Method
2. The BET Apparatus Method
3. The Brenauer-Emmett-Teller Method

The specific surface as measured by the BET method includes not only the exterior but also the interior surfaces (pure surface) of the powder. The other methods measure only the specific surface due to the exterior of the powder.

(3) Simulated Behavior Test: Tests simulating powder behavior in fabrication are widely used to determine the following characteristics:

(a) Compressibility of Powder
(b) Green Strength of Powder Compacts

(a) Compressibility of a metal powder is an important physical characteristic. It is affected by the physical properties and size distribution of the particles. From the standpoint of pressing, the compressibility characteristic is very important to the fabrication of P/M parts and the mechanical properties to be obtained therefrom. Powders should have good compressibility so that satisfactory green and final densities can be achieved without using excessive pressures. Compressibility is expressed as the compression ratio of the powder. The compression ratio is the quotient of the apparent density of the powder divided by the pressed density of the pressed shape at any stage of the pressing operation. For the max compressibility ratio it is the apparent density divided by the theoretical density.

(b) Many powder producers prefer to express the green density characteristics of their powder rather than the compressibility ratio. Details of the procedure are given in ASTM Specification No. B331. In this test the metal powder is pressed into a compact $1\frac{1}{4}$" long, $\frac{1}{2}$" wide, and $\frac{1}{4}$" thick to a standard density for the particular metal powder being tested. The green

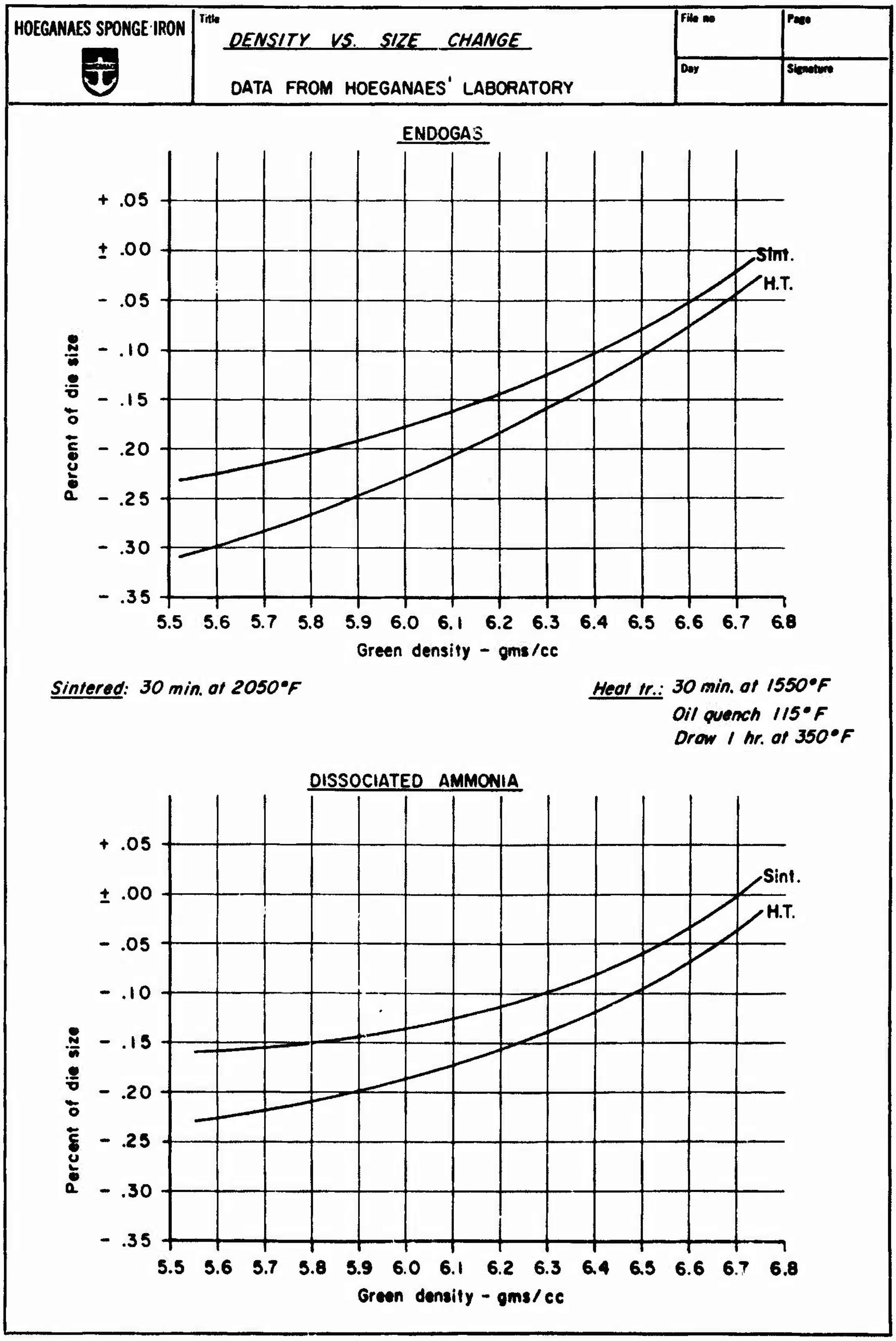
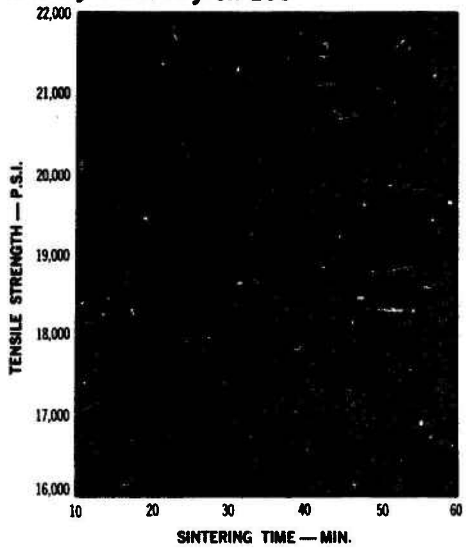


Figure #26
Courtesy of Hoeganaes Sponge Iron Corporation

GRAPH NO. 3

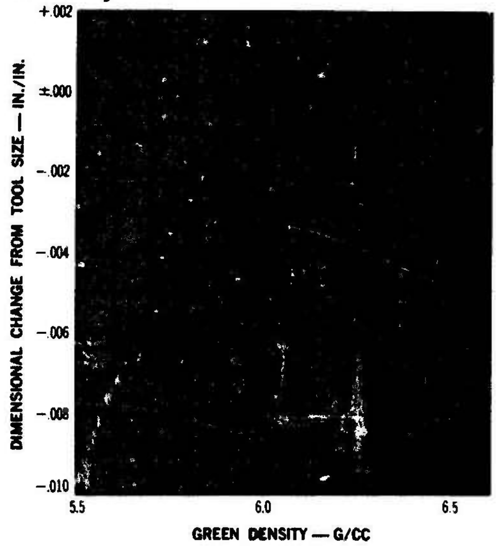
Tensile Strength vs Sintering Time & Sintered Density 100% Pyron 100



Test Conditions: Sintering temp 2050F
Time as shown
Atmos H_2

GRAPH NO. 4

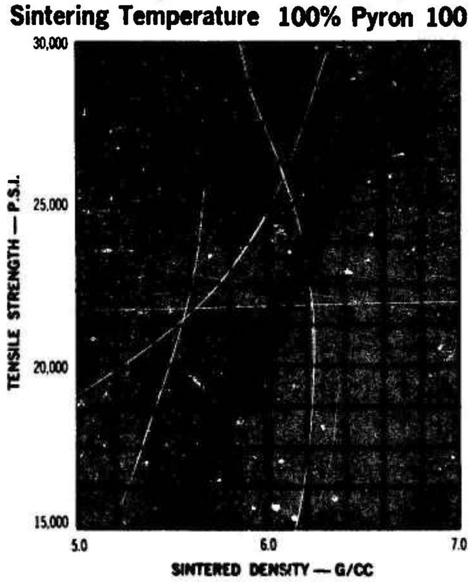
Dimensional Change vs Green Density 100% Pyron 100



Test Conditions: Sintering temp 2050F
Sintering time 45 min
Atmos H_2

GRAPH NO. 5

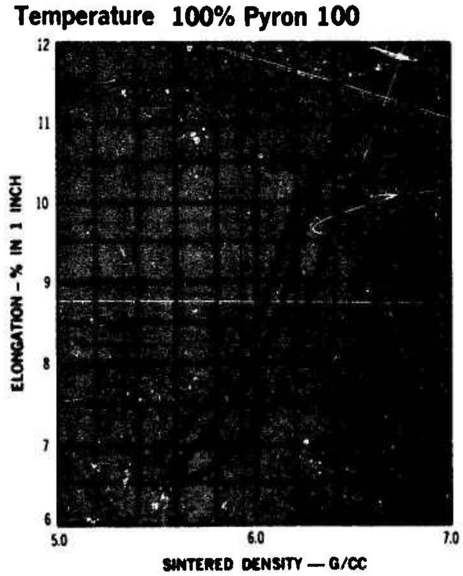
Tensile Strength vs Sintered Density & Sintering Temperature 100% Pyron 100



Test Conditions: Sintering temp as shown
Sintering time 45 min
Atmos H_2

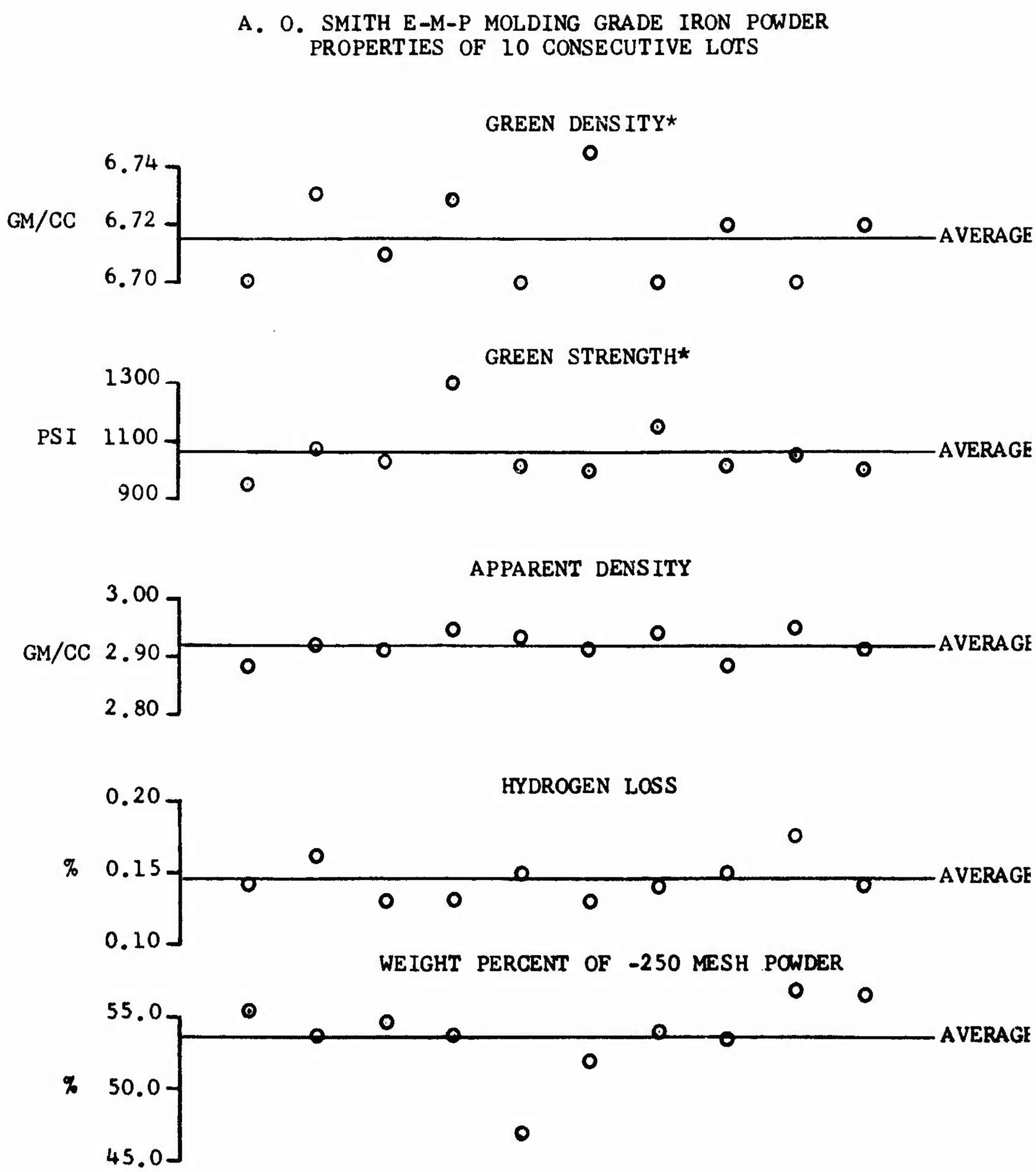
GRAPH NO. 6

Elongation vs Sintered Density & Sintering Temperature 100% Pyron 100



Test Conditions: Sintering temp as shown
Time 45 min
Atmos H_2

Figure #27
Courtesy of American Metal Climax, Inc.
Pub. MP/65-2



*GREEN PROPERTIES DETERMINED ON TEST SPECIMENS PRESSED AT 30 TSI WITH 0.5% ZINC STEARATE.

Figure #28
Courtesy of A. O. Smith Corporation

A. O. SMITH E-M-P MOLDING GRADE IRON POWDER

Additions to Powder	Compacting Pressure (tsi)	Green Density (gm/cc)	Green Strength (psi)	Sintered Density (gm/cc)	Modulus of Rupture (psi)	% Dimensional Change*	Yield Strength (psi)	Tensile Strength (psi)	Elongation % in 1"	As Sintered Hardness
0.5% Zinc Stearate	30	6.72	1100	6.73	68,000	–.03	15,000	23,000	7	38 R_f
	50	7.23		7.25	109,000	.04	20,000	32,000	10	59 R_f
0.5% Zinc Stearate 0.5% Graphite	30	6.74	1000	6.74	84,000	.01	27,000	36,000	2	38 R_b
	50	7.22		7.22	124,000	.07	34,000	49,000	3	55 R_b
0.5% Zinc Stearate 0.9% Graphite	30	6.75	900	6.72	121,000	.10	38,000	55,000	2	61 R_b
	50	7.18		7.17	165,000	.17	47,000	73,000	2	74 R_b
0.5% Zinc Stearate 0.9% Graphite 2% Copper	30	6.79	1000	6.72	161,000	.22	61,000	79,000	1	81 R_b
	50	7.19		7.18	216,000	.36	76,000	99,000	2	92 R_b

* % Change from die size after sintering

Sintered 15 to 25 minutes at 2050°F in dissociated ammonia

Data: Lubricant and graphite mixes – Average of 13 lots (3 specimens for each test for each lot)

Graphite and copper mix – Average of 5 lots (3 specimens for each test for each lot)

Additions: Zinc stearate, Matheson, Type 2X – 100
Graphite, Dixon, Type 200 – 43
Copper, American Metal Climax, Type AMAX – M

Figure #29
Courtesy of A. O. Smith Corporation

A. O. SMITH E-M-P MOLDING GRADE IRON POWDER
0.5% ZINC STEARATE - 0.9% GRAPHITE - 2% COPPER
SINTERED IN DISSOCIATED AMMONIA

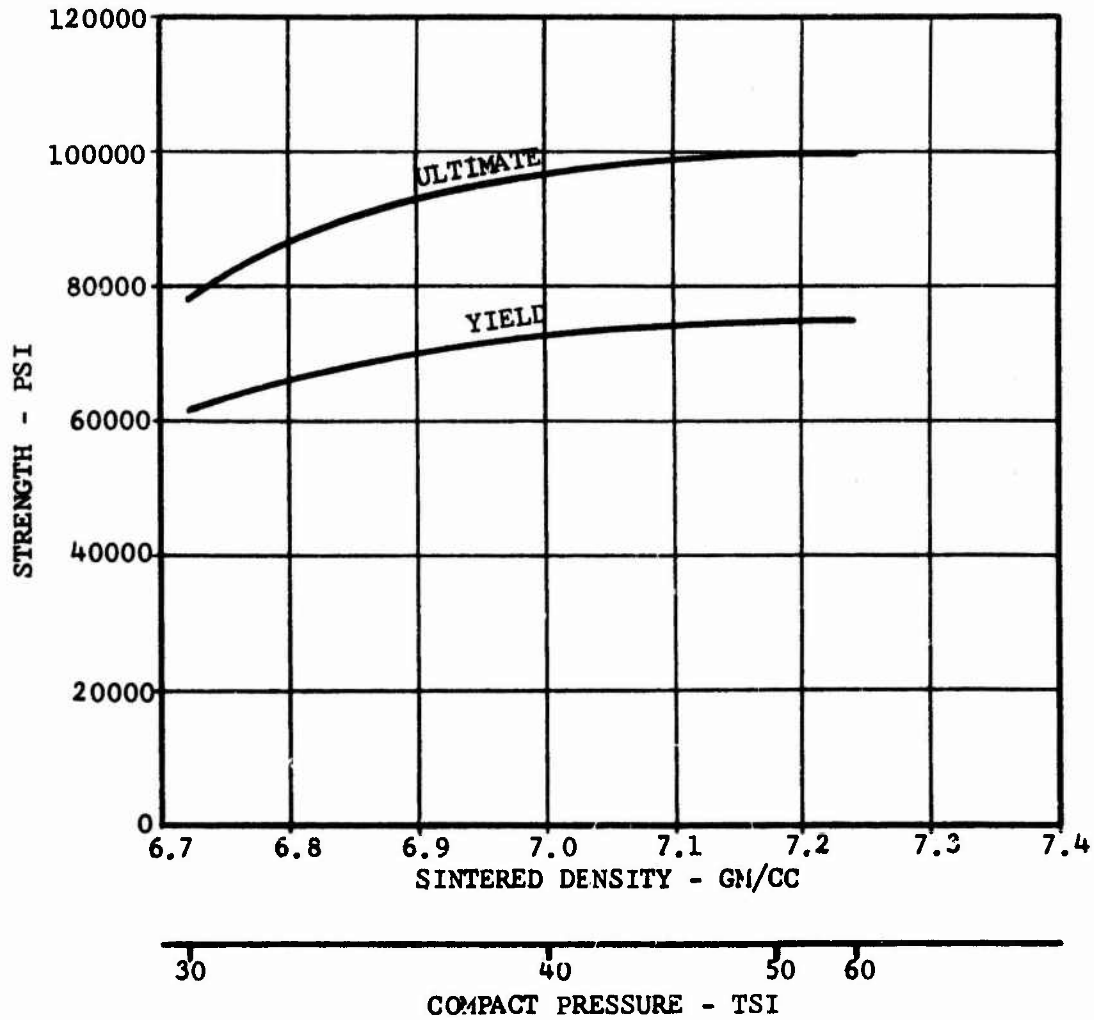
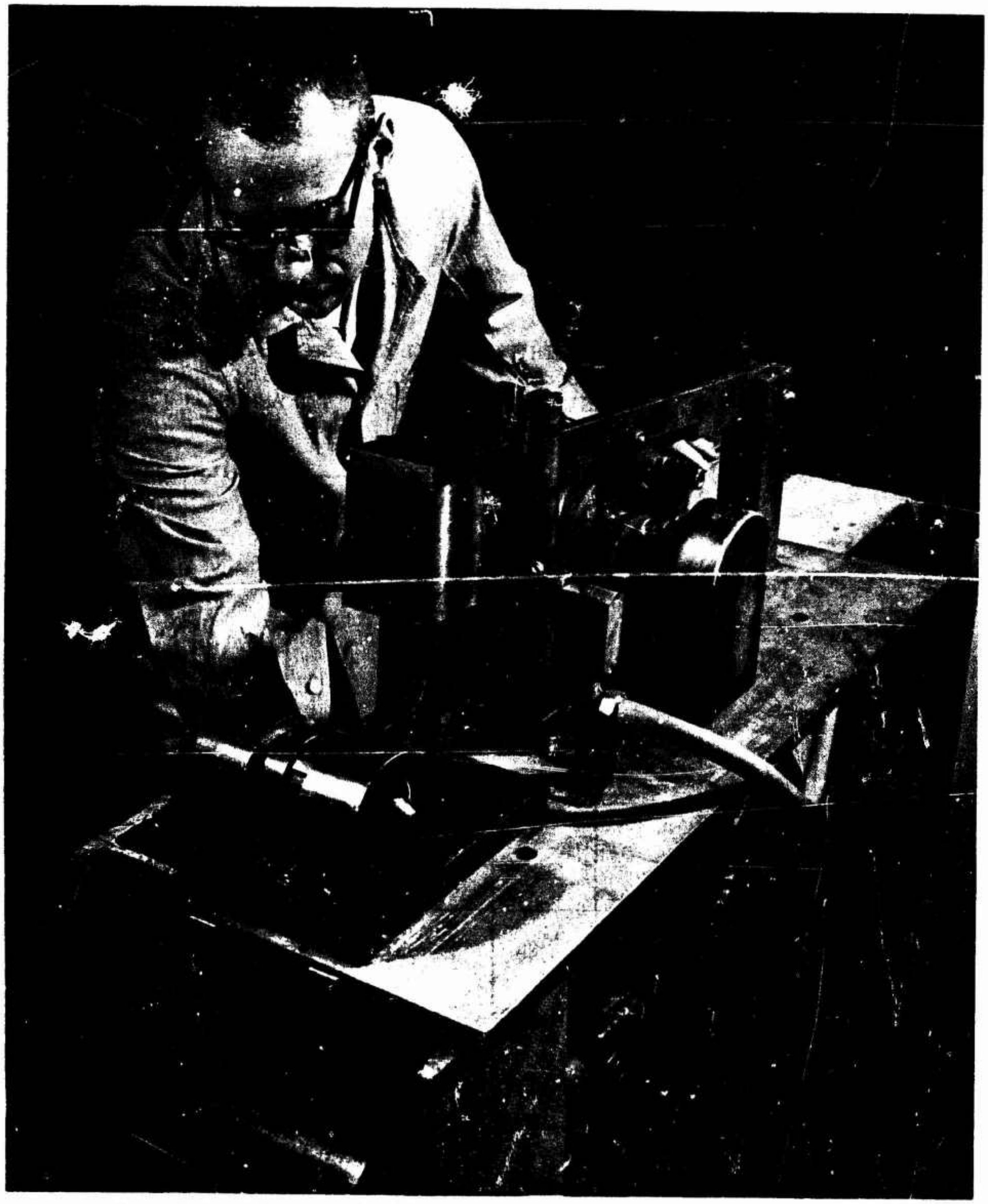


Figure #30
Courtesy of A. O. Smith Corporation



Impact testing production parts as a Quality Control check and production surveillance procedure.

Figure #31
Courtesy of Keystone Carbon Company

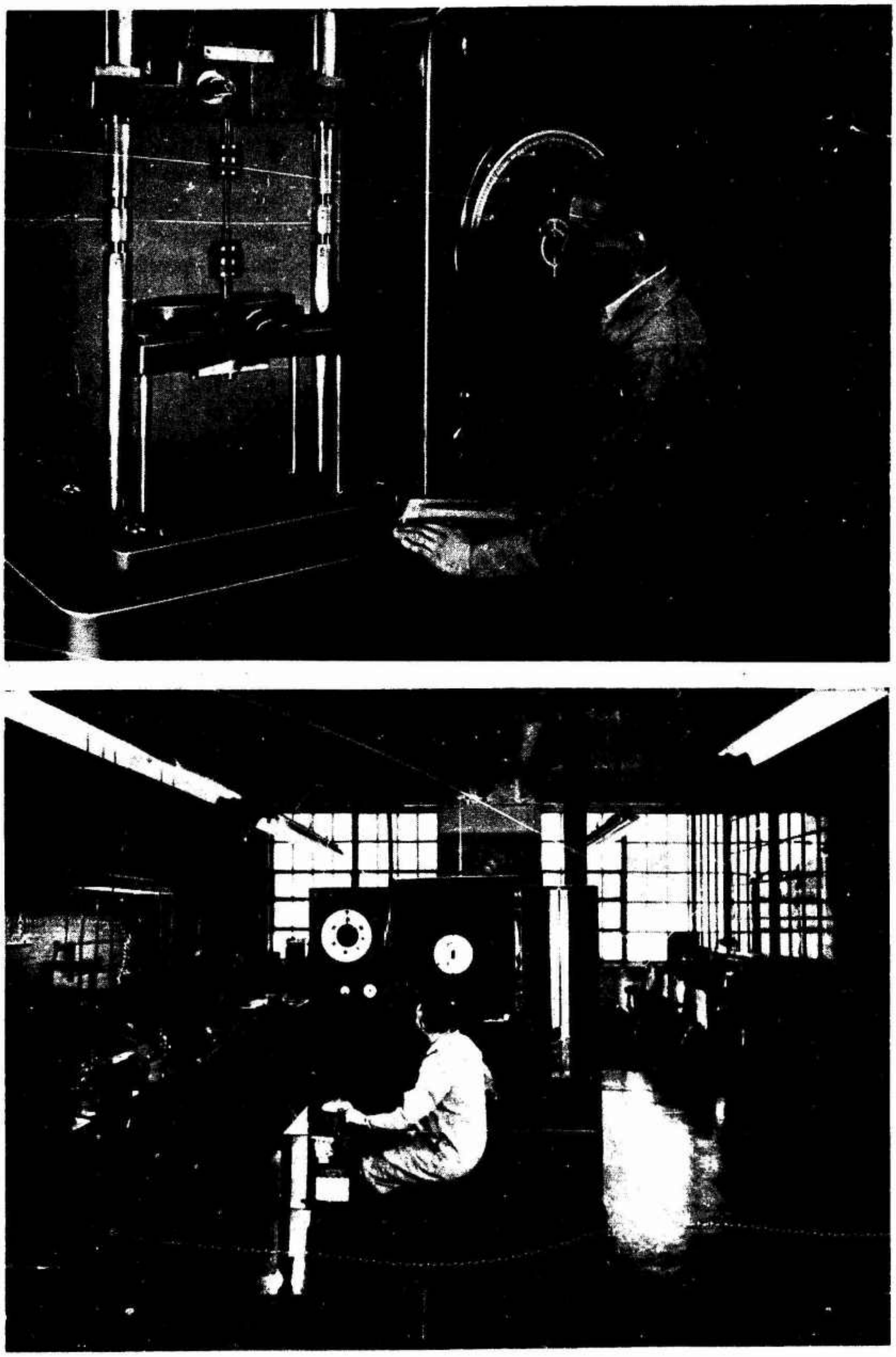
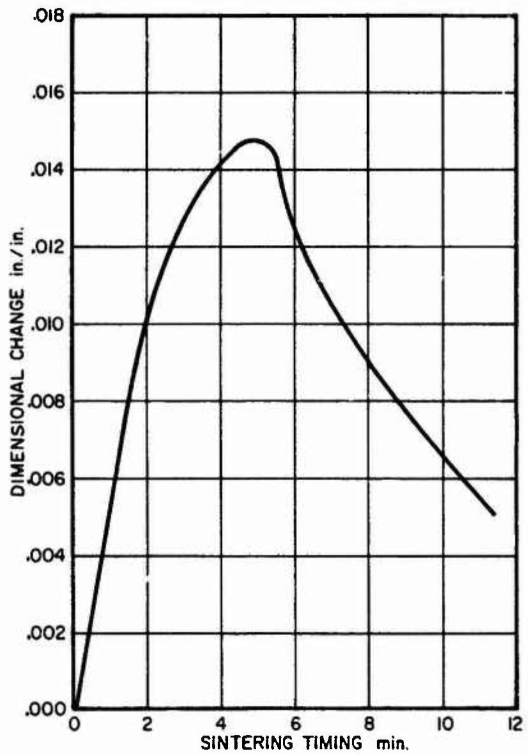


Figure #32

Reprinted by special permission from The United States Graphite Company, Division The Wickes Corporation from GRAMIX Engineering Handbook G-55, Copyright 1955.



Graph 3. Dimensional Change vs Sintering Time 90% Cu/10% Sn AMAX Pre-Mixed Bronze Powder

Figure #33
Courtesy of American Metal Climax Inc. Bull. MP/65-1.

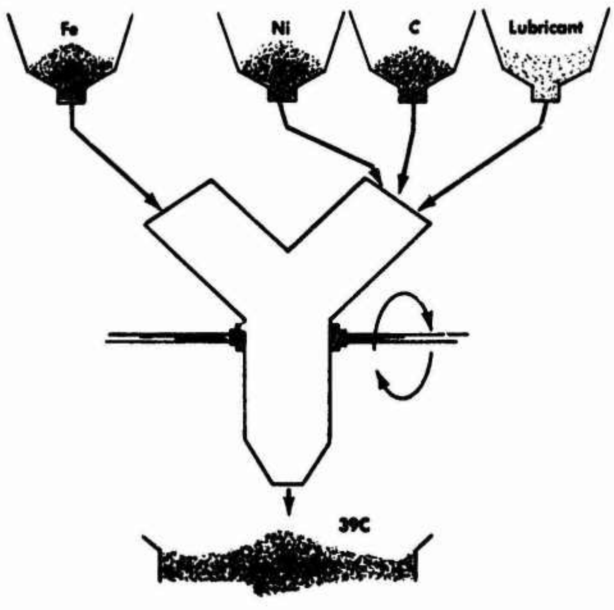
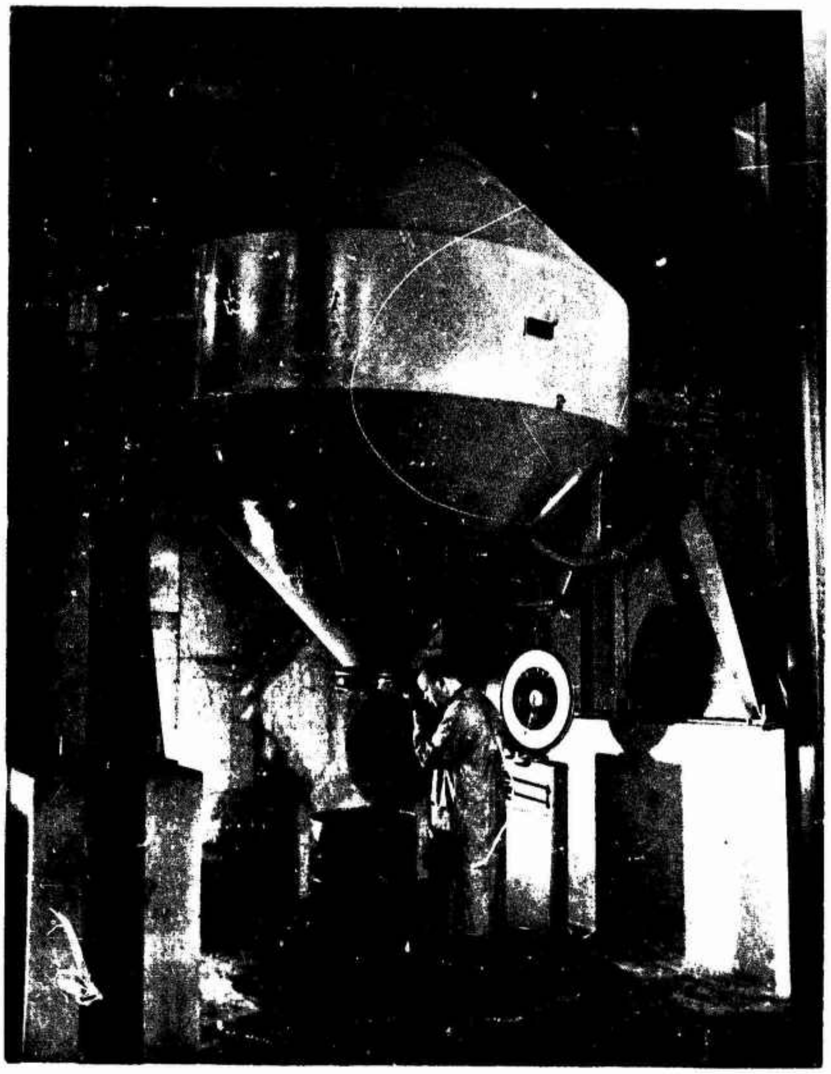


Figure #34
Reprinted by special permission from Wakefield Bearing Corporation, Copyright 1965.

specimen is tested by applying a load in a standard set-up to determine the load required to break the test specimen. The green strength is calculated from the rupture load. Other tests are used to determine the behavior of metal powder in processing. Some of the other characteristics and properties to be measured are shrinkage during sintering (Figure #33), mechanical properties, porosity, etc. (Figure #31). None of these tests are standardized and therefore no industry or Federal specifications exist except proprietary ones.

d. <u>Powder Blending</u>: Blending or mixing of metal powders or lubricants is a very important processing operation. P/M parts fabrication employs the operation to exercise control over their materials for the fabrication of parts (Figure #34). To insure that their powder materials are uniform from one lot to another for producing second order or follow on orders the fabricator has to exercise precise control over the composition of the mix. Powder manufacturers also blend powder for commercial use or to the fabricator specifications, but most P/M parts producers prefer to blend their own mix.

One of the more important blending operations used by the fabricators is the blending of lubricants into the powder to reduce die-wall and powder friction during the pressing operation and to reduce die-wall friction upon ejection of the green compact from the die. Most of the lubricants used for the elimination of die-wall and powder friction are metallic stearates, stearic acid and where possible graphite. The stearates are voltatized or decomposed during the sintering cycle and do not impair the compacts if quantities are mixed correctly. The small residue that may remain is not considered detrimental to P/M parts. Graphite is an excellent lubricant but can be used only if the part can contain carbon because it does not voltatize but alloys during the sintering process.

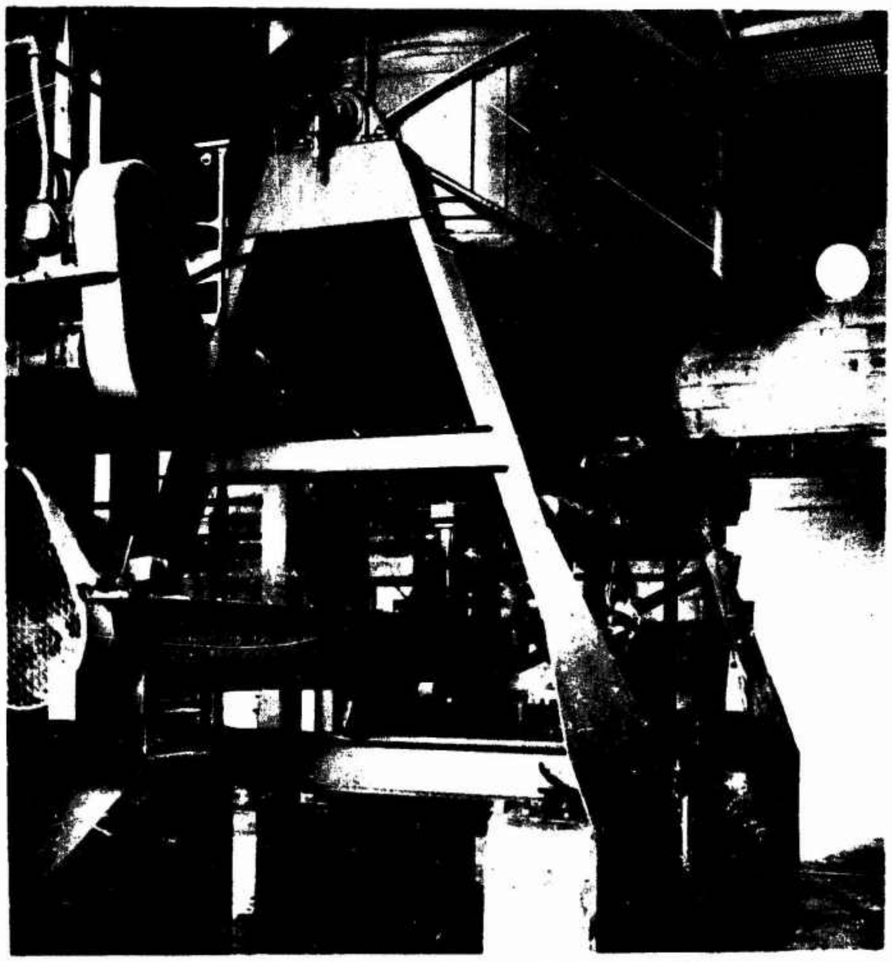


A blender typical of those used for blending metal powders at Keystone Carbon Company, St. Marys, Pa. The blender has capacity of 35,000#.

Figure # 35
Courtesy of Keystone Carbon Company

Blending is also used to homogenize large lots of powders, to mix various grades of the same powder, to mix different powders of the same base metal, to mix other metal powders, and to mix nonmetallic materials. The blended mixes are used to produce P/M

"The uniformity of properties of powder mixes is as important as the properties themselves. Without such uniformity, long production runs are impossible except with costly compensatory equipment adjustments. Most fabricators are not equipped with the large-capacity equipment required to



35,000-lb. blender used to pre-mix Pyron iron with copper, carbon, and other additives in ready-to-compact truckload lots.

Figure #36
Courtesy of American Metal Climax, Inc.
Pub. MP/65-3

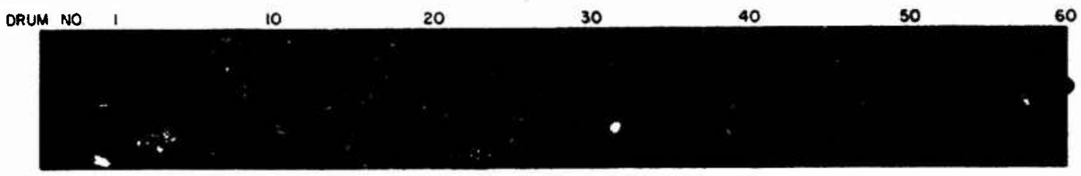
mix the large quantities of powders necessary for trouble-free mass production. Many therefore take advantage of AMAX's pre-mixing service and order combinations of powders and additives pre-mixed, ...

"powders in up to 35,000-pound quantities, mixed at a single time, completely uniform throughout. In addition to the savings realizable on the production line, pre-mixed powders offer such advantages as reduction of storage space and inventory and elimination of the handling equipment needed for in-plant mixing."[1]

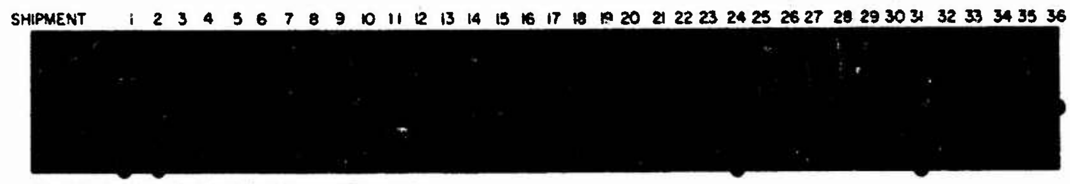
structural parts of metal alloys. The alloying is accomplished during the sintering process.

Typical Performance Data for Pyron Iron/Copper Pre-Mix

The experience data presented in Graph 1 shows the drum-to-drum uniformity of sixty 500-pound drums making up a single 30,000-pound mix of AMAX/Pyron Iron/Copper Powder. Apparent density varies only 0.01 g/cc over the entire sixty drums. Shipment-to-shipment uniformity of AMAX/Pyron pre-mixed powder parallels uniformity within each shipment. This is indicated by Graph 2. In thirty-six consecutive lots of one grade of pre-mixed powder, totalling over 1,000,000 pounds, apparent density varies less than 0.1 g/cc.



Graph 1—Apparent Density Throughout Shipment of Sixty 500-lb. Drums: Range 0.01 g/cc



Graph 2—Apparent Density of 36 Consecutive Shipments

Figure #37
Courtesy of American Metal Climax, Inc., Bull. MP/65-1.

It is important to use equipment that requires uniform mixing of the desired proportions in a minimum of time. Usually a long blending cycle will cause the powders to segregate or agglomerate which produces a poor mix or blend. It is best to use the minimum time possible to accomplish the operation. A method used to offset the undesired problems is to mix a small fraction of an organic additive, possessing adhesive qualities, such as camphor, lauryl alcohol or similar organic additives. In some cases satisfactory results are obtained by coating the heavier or matrix powders with the additives before blending with the other powder materials. Additives also tend to equalize the different particular shapes and cause a better homogeneous mix with powders of spherical and irregular shapes. Uniform mixtures can be easily obtained with different powders of irregular shapes and apparent density.

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[1] Courtesy of American Metal Climax, Inc., Pub. MP/65-3.

e. Metal Powder Pressing:

(1) Compacting Process
(2) Compacting Presses

(1) The first fabrication or configuration of a P/M part begins with the pressing process. In most cases the first serious problems to be encountered in the powder metallurgy process are usually found when pressing powder into shapes. This phase of the powder metallurgy process is referred to as compacting or pressing. Compacting or pressing of metal powders is divided into the following two areas:

(a) Hot pressing
(b) Cold pressing

(a) Hot pressing is the compaction of powder at elevated temperatures. It is usually a dual technique where the metal powders are compacted and sintered at the same time. Because the hot pressing technique is used mostly in the manufacturing of carbide cutting tools and in a few specialized applications this process will be treated in a supplement follow-on to this P/M journal.

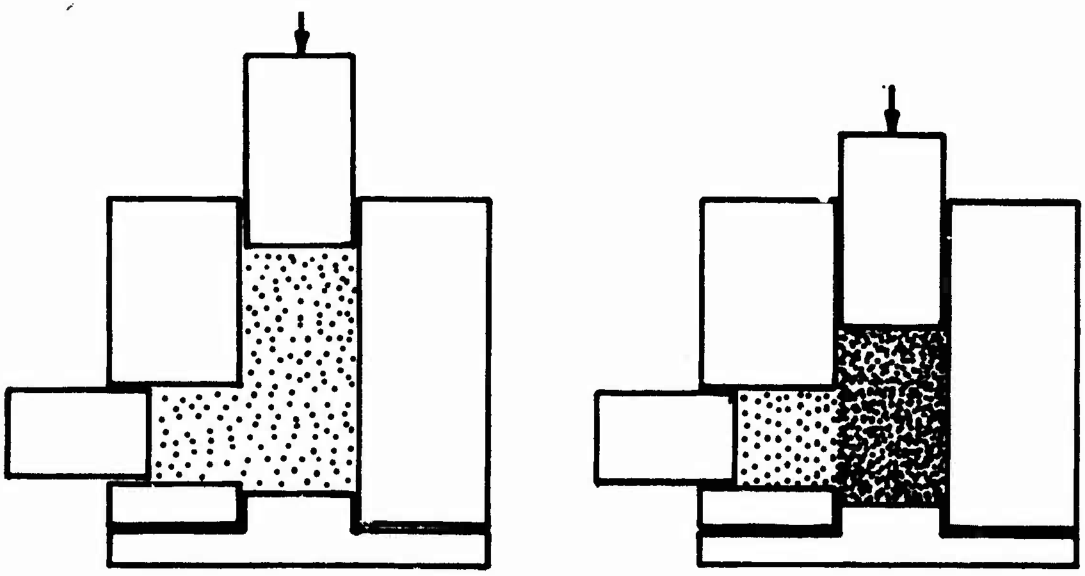
(b) Cold pressing can be further divided into the following processes:

1. Axial pressing (for the rest of this discussion denotes conventional pressing)

2. Isostatic pressing-----a unique technique where pressure is applied uniformally to the metal powders which are usually contained in bags made of plastic or rubber. The pressure is applied by a liquid and in some special cases a gas is utilized as the pressure transferring medium. Isostatic pressing will also be discussed in more detail in the supplement follow-on to this journal.

Cold pressing is the method of applying pressure upon a column of loose (apparent density) metal powders in a closed die to form a green compact. This method of compaction is used more than any other and accounts for the great majority of parts fabricated by the powder metallurgy process.

To better understand the pressing operation a few important principles involved in the process will be discussed. It has been found that powders do not behave under pressure, in a closed die, in the same way as a liquid. Pressure exerted on a liquid in a closed container is transmitted hydrostatically (evenly in all directions). This is not the case with metal powder. When metal powders are pressed in a closed die they flow mainly in the direction of the applied pressure. Seldom is there any large horizontal movement of the powders in the die under axial pressure (Figure # 38a).



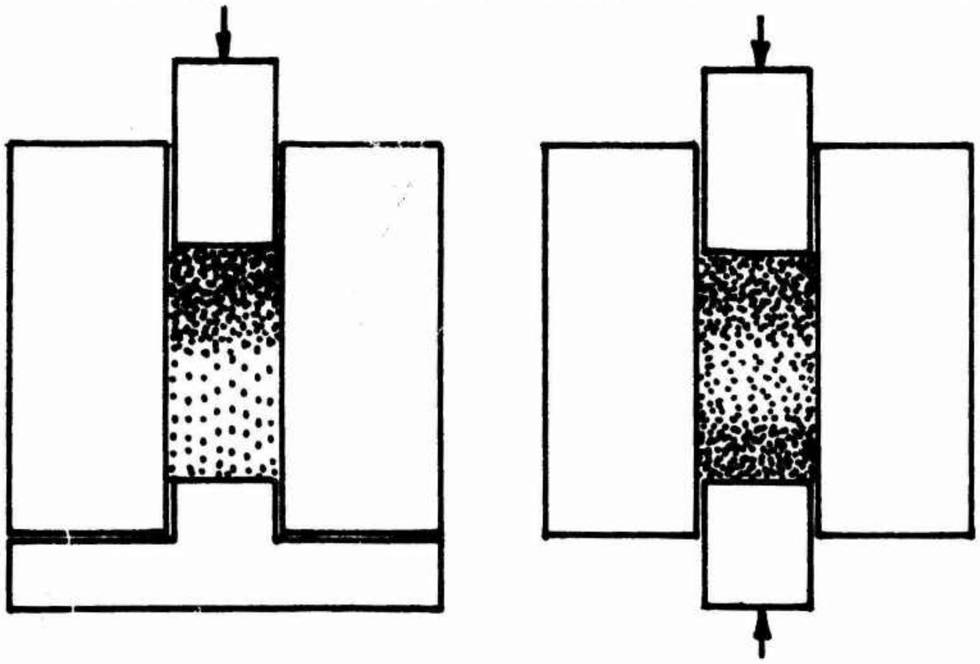
(a) (b)

Figure # 38

It can be seen from the illustration in Figure #38 the effects of pressure on powders in a closed die. Figure (a) is the powder before pressing and Figure (b) is the compact after pressing. It can be seen that the powders under the direction of pressing are more dense than the powders to the left (Figure (b)). The horizontal section to the left did not densify because of lack of horizontal pressure.

The effects of pressure on metal powders depend on a number of variables and included among them is the powder itself. Pressing of metal powders depend upon their physical characteristics and properties. These include particle size, shape, composition, and size distribution. The type of powder and its method of manufacture also influences its behavior under pressure in a closed die. Generally coarse powders require less compacting pressure than fine powders, but on the other hand they may require higher compacting pressures to obtain equivalent (higher) densities of fine metal powders possessing the same apparent density for the fabrication of the desired P/M shapes. It has been found that smooth powders of spherical shapes press more readily than those of irregular shape and require less compacting pressure. On the other hand deformability of smooth powders is inferior to irregular shaped powders and requires higher pressures for greater green strengths. Concerning compressibility, hard powders require greater compacting pressures than softer particles of the same structure and composition to achieve equal or satisfactory densities in the compact. Generally, better green densities can be obtained with irregular shaped powders.

At the present time all pressing operations using mechanical-hydraulic equipment exert pressure upon the compact in a vertical direction. The pressure can be applied from the top, from the bottom, or from the top and bottom (Figure # 39). In actual practice



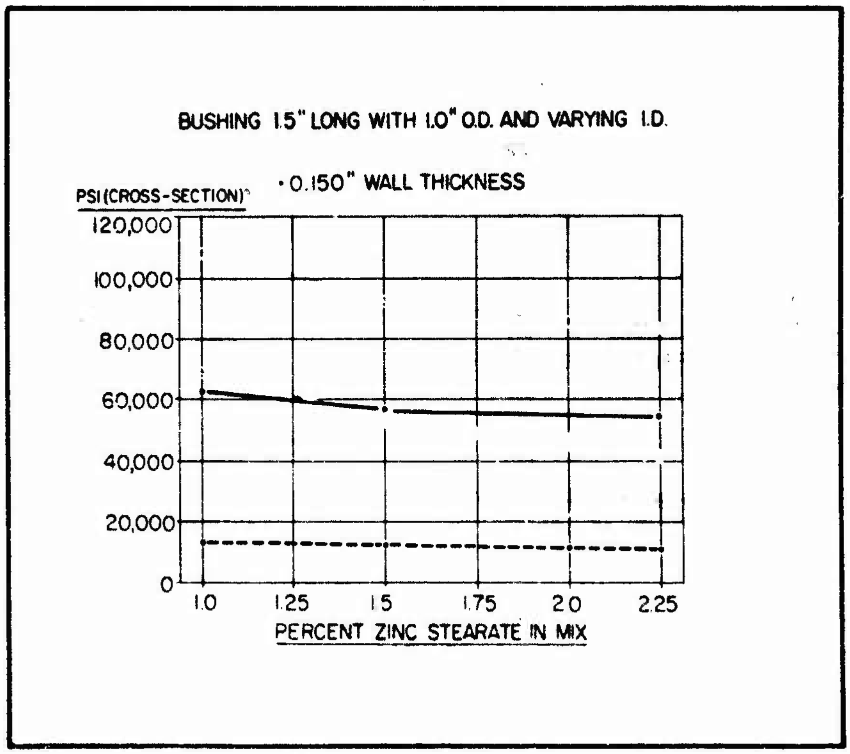
Pressure from Top
(a)

Pressure from Top and Bottom
(b)

Figure #39

most pressing operations utilize top and bottom pressure upon the compact. Parts compacted by pressure applied from both top and bottom are more dense from the top and bottom than at the center depending on the height of the green shape (Figure #39 (b)). Usually it is important that the density of the compact be as uniform as possible throughout its entire height.

If pressure were applied isostatically (from all directions) internal pressure distribution would reduce pressure loss due to friction. The uneven distribution of density in a compact is caused by pressure not being transmitted through the green shape without a drop (loss) due to friction. The influence of die friction upon the density distribution in compacts is an important consideration in producing parts. Compacting parameters must be worked out to compensate for this phenomenon in producing parts of comparative uniform density. The loss of compacting pressure throughout the green shape is not too important in flat thin compacts, but uniform density is impaired in compacts of thicker sections. Uniform density is essential to insure dimensional consistencies during sintering. Lubricants, as mentioned previously under powder blending, are mixed with most metal powders to eliminate or ease to a lesser degree friction between powders and between die wall and powder (Figure #40).

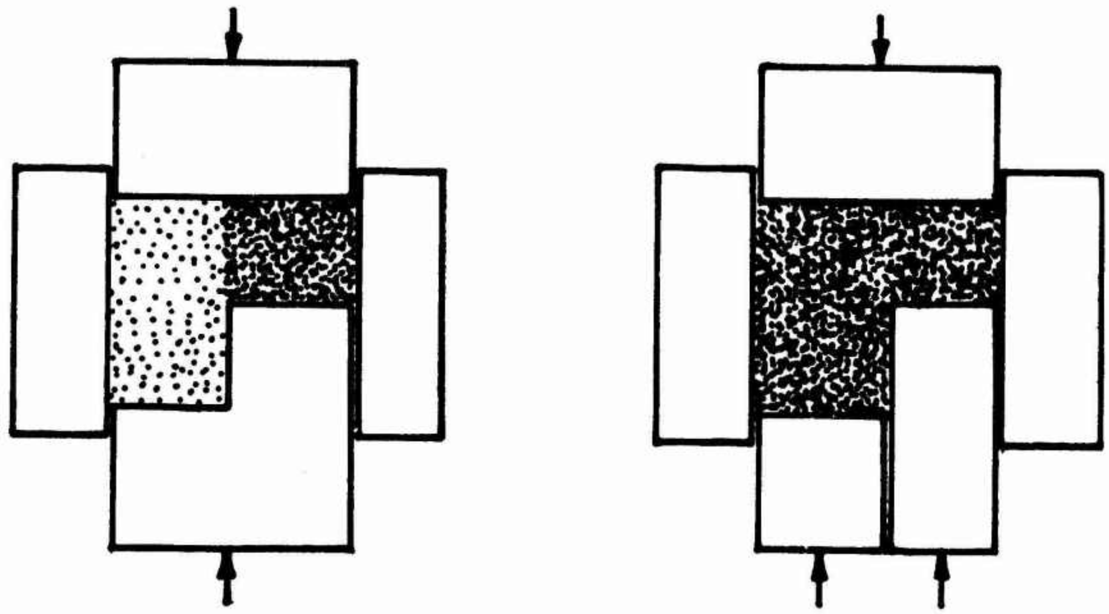


BRIQUETTING AND STRIPPING PRESSURES VS. PERCENT ZINC STEARATE IN MIX

Figure #40
Courtesy of Hoeganaes Sponge Iron Corp.
Bull. No. 142 1M, 6/65

"Figure #40 shows the influence of the wall thickness of a bushing on briquetting and stripping pressures (when the bushing is pressed to constant green density). When the briquetting and stripping pressures are figured on the cross section of the part, they both decrease with increasing wall thickness of the bushing. It is "also apparent that the percentage of lubricant added is more important for the bushing with the thinner wall. An increase in the percentage of lubricant gives lower briquetting and stripping pressures."[1]

Relative to the phenomenon of metal powder flow is the secondary fact that parts which vary in thickness in the direction of pressing will vary in density unless provisions are made (usually in the die tools) to equalize the compression ratio in the sections which vary in thickness or cross sections (Figure #41). The thick-



(a) (b)

Figure #41

ness of each level will determine whether the pressing force must be applied from just one or both directions (top and bottom). On parts with more than one level the pressing forces must be applied separably to all levels simultaneously.

In Figure #41(a), the effects of pressure, transmitted through a single punch, on shapes of varying thicknesses can be visualized. The section to the right in the die is more dense than the section to the left. This is due to the compression ratio of the powder and the height of the levels to be pressed. The section to the left

[1]Courtesy of Hoeganaes Sponge Iron Corporation, Bull. No. 142 1M, 6/65.

requires a longer stroke of the punch to achieve equal densification than the section to the right. In Figure #41 (b) a schematic diagram of a split punch is used to illustrate the variation in pressing that is required to achieve equal densification and compression ratio throughout a green compact of varying thickness. Powder is unrestrained while porosity still exists in the green compact, consequently a little pressure will cause a large volume of powder to move. As the pressing operation proceeds and the porosity of the metal powder dimenishes the powder in the closed die becomes totally compacted by the die wall and punches as the pressure reaches its maximum.

In pressing any P/M part, whether simple or varying in shape it is important that the compression ratio remains the same (constant) throughout the cross section of the part. Compression ratio, as expressed before, is the apparent density over the pressed density, in other words the volume of the metal powders pressed in a closed die is proportional to the volume of the loose powders in the filled die before pressure is applied. The actual volume of the pressed part can be expressed as a fraction of the initial volume (filled die) by the following relationship:

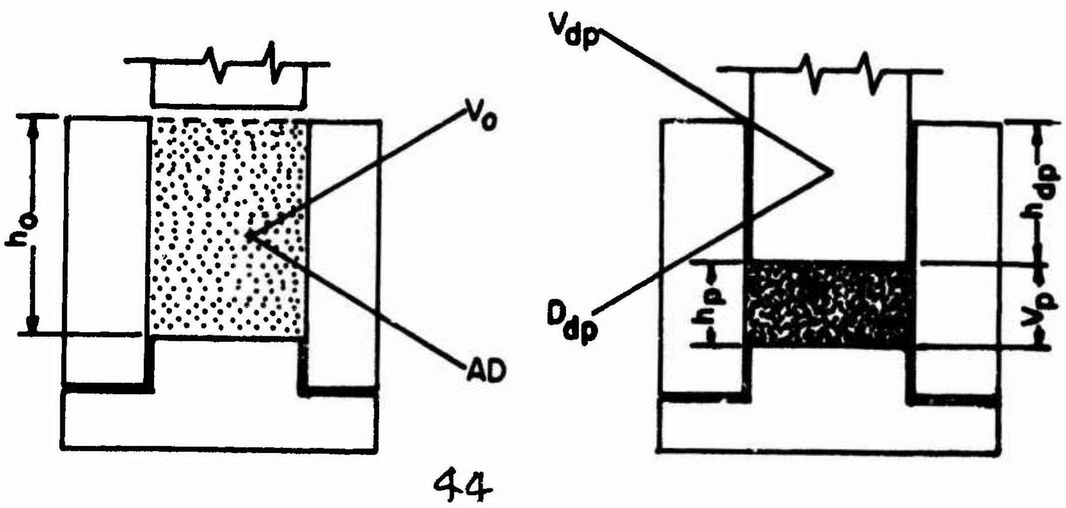
$$V_p = V_o \left(\frac{V_o - V_{dp}}{V_o} \right)$$

Where:

V_o = Initial Volume of loose powders

V_p = Pressed Volume of Compact

V_{dp} = Displaced Volume of Powders



(a) (b)

Figure #42

By the same reasoning the pressed height and pressed density of the green compact can be expressed as a fraction of the originals.

$$h_p = h_o \frac{(h_o - h_{dp})}{h_o} , \qquad PD = AD \frac{AD - D_{dp}}{AD} = AD \frac{AD - (AD - PD)}{AD}$$

Where:

h_o = initial height (filled die) of powder
h_p = pressed height of compact
h_{dp} = displaced height of powder

AD = Apparent Density of Powder
PD = Pressed Density of Green Compact
D_{dp} = Apparent Density minus Pressed Density

Because of the following relationships:

$$\frac{h_o - h_{dp}}{h_o} = \frac{V_o - V_{dp}}{V_o} = \frac{AD - D_{dp}}{AD}$$

The fractions obtained from the above expressions can be converted into compression ratios by taking the reciprocal of the fraction.

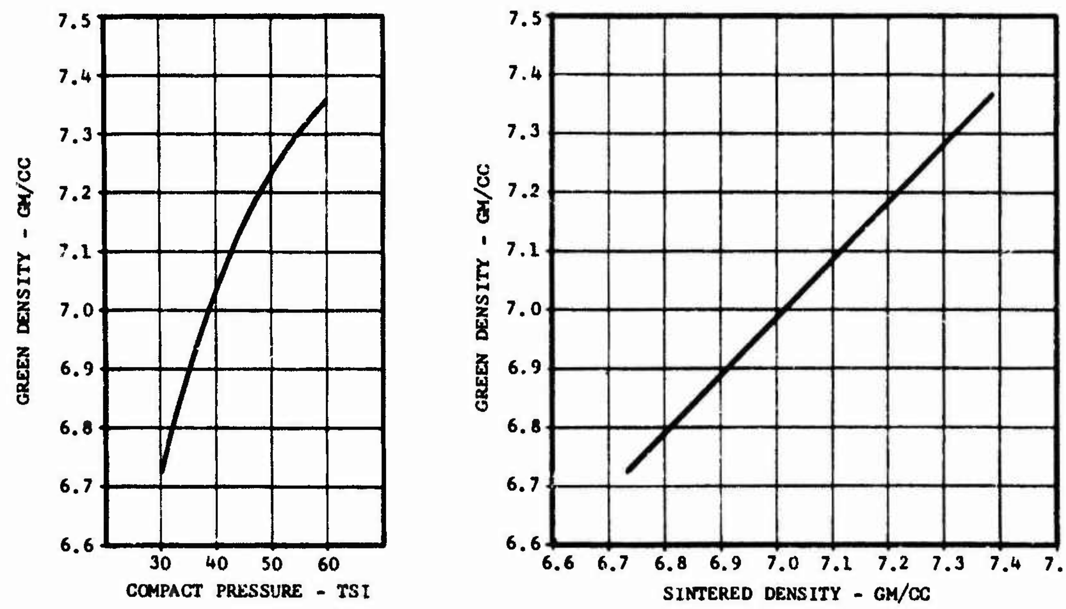


Figure #43
Courtesy of A. O. Smith Corporation

TONNAGE REQUIREMENTS AND COMPRESSION RATIOS FOR VARIOUS POWDER PRODUCTS

Type of Compact	Tons Per Sq. Inch	Compression Ratio
Brass parts	30 to 50	2.4 to 2.6:1
Bronze bearings	15 to 20	2.5 to 2.7:1
Carbon products	10 to 12	3.0:1
Copper-Graphite brushes	25 to 30	2.0 to 3.0:1
Carbides	10 to 30	2.0 to 3.0:1
Alumina	8 to 10	2.5:1
Steatites	3 to 5	2.8:1
Ferrites	8 to 12	3.0:1
Iron bearings	15 to 25	2.2:1
Iron parts:		
low density	25 to 35	2.0 to 2.4:1
medium density	35 to 40	2.1 to 2.5:1
high density	35 to 60	2.4 to 2.8:1
Iron powder cores	10 to 50	1.5 to 3.5:1
Tungsten	5 to 10	2.5:1
Tantalum	5 to 10	2.5:1

The above tonnage requirements and compression ratios are approximations and will vary with the chemical, metallurgical and sieve characteristics, and with the amount of binder or die lubricant used.

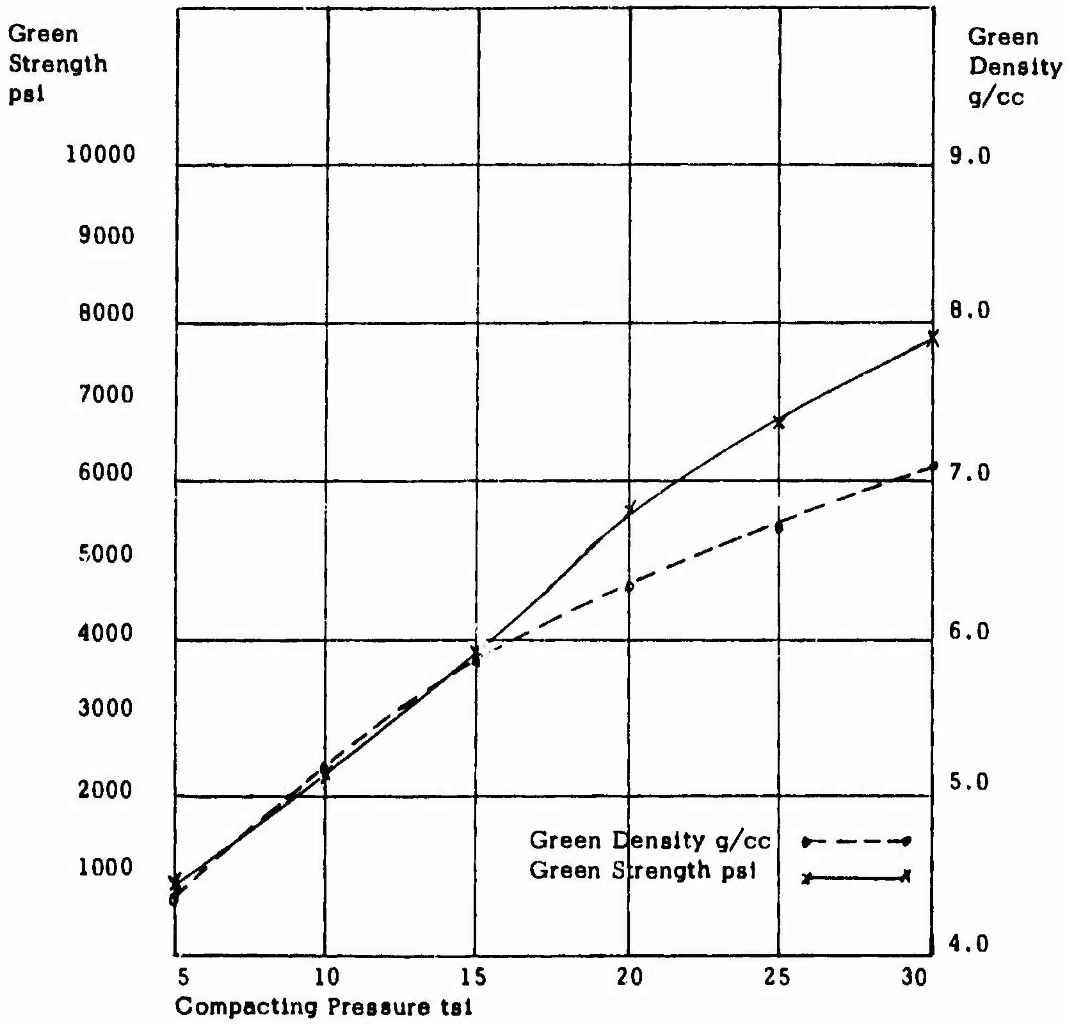
Figure #44
Reprinted by special permission from Metal Powder Industries Federation from Powder Metallurgy Equipment Manual, Part II, Compacting Presses and Tooling, (C) 1965

In the majority of cold pressing methods the presses operate either with a definite stroke or a specified pressure. If the press operates to a definite stroke the pressure can be kept constant only if the apparent density of the metal powder is constant.. Consistency in apparent density is also required to insure compacts of uniform length if the press operates to a specified pressure. Minor differences in apparent density can usually be compensated for by adjusting the pressure or the stroke of the press. Uniform density is important to insure dimensional consistencies during sintering.

The compacting pressures for fabricating most P/M parts may range from 20,000 PSI to approximately 200,000 PSI. Generally pressures do not exceed 100,000 PSI except in cases where unusual mechanical properties are desired for the part. The pressure required to obtain a given green density depends upon the metal powder material being pressed (Figure # 43). This force ranges from 3 tons to 60 tons per square inch of surface area (Figure # 44).

Excessive pressures can present some complexing problems such as punch and die fractures, slip cracks and cleavage fractures in the greens parts, freezing of the green compacts to the die; and fracture of the green shapes upon ejection from the die. Although high pressures are required for pressing high density shapes they should not be too excessive as to cause deformations to the die, punch, and press; otherwise dimensional tolerances cannot be controlled and maintained for the P/M part.

VM 120-90
Versametal Copper Powder
Compacting Pressure versus Green Strength and Green Density



VM 120-90

Compacting Pressure tsi	Green Density g/cc	Green Strength psi
5	4.32	980
10	5.20	2380
15	5.85	3840
20	6.33	5640
25	6.70	6770
30	7.10	7680

Figure #45
Courtesy of Universal Minerals and Metals Inc.

Another pressing operation usually performed on P/M parts when required is sizing or repressing. Generally this operation is performed after the first sintering operation. This special pressing operation is frequently necessary to hold dimensional tolerances beyond the capacity of the green compacting operations. When extremely accurate dimensions are required the P/M part or parts must be resized because of dimensional changes during the sintering operation. This is a rapid operation usually performed in high speed presses. A similar operation is frequently employed to increase the density of a sintered or pre-sintered part. This operation is referred to as "coining". It is used to strengthen and densify parts requiring above average mechanical properties. Occasionally the sizing and coining operations are combined into a single operation depending upon the requirements of the P/M parts. In some cases it may be necessary to coin or size one or more times. For the majority of P/M parts, to obtain medium densities, the coining operation is relatively simple. Occasionally parts such as gears and pinnions are pressed and sintered over size then pressed to actual size for greater dimensional control.

(2) Compacting Presses: The principal steps in the process of compacting metal powders with presses are:

(a) Feeding the powder into a die cavity
(b) Compacting the powder into the required shape by applying pressure.
(c) Removing the shaped part from the press

The means for applying pressure to powder metals in a closed die are:

(a) Mechanical Presses
(b) Mechanical-Hydraulic or Pneumatic
(c) Hydraulic
(d) Isostatic
(e) HERC Techniques

Isostatic presses and HERC Techniques for compacting metal powders will be discussed in a supplement to this journal.

Generally the minimum requirements for powder-metal presses are:

(a) Adequate compacting pressure (applied in the desired direction---usually vertical).
(b) Controlled length of stroke (both for pressing and ejecting the green shape).

Sizing operation on pressure plate made of iron powder.

Figure #46
Courtesy of Keystone Carbon Company

(c) Rate of stroke (speed of pressure)
(d) Adjustable die fills
(e) Rigidity and protection from the abrasive action of the metal powder
(f) Simplified and minimum lubrication schedules

For multiple-motion presses synchronization and control of the press stroke for powder transfer and other operations are a prime necessity.

The earlier presses used for compacting metal powders were developed by alternating or modifying pill (pharmaceutical) and small stamping presses. The modified pharmaceutical and stamping presses possessed poor rigidity characteristics consequently, good punch and die alignment could not be maintained. They also required quite a bit of set-up time to change dies and punches because of the lack of adjustability and controls. The tonnage capacity of the modified pressing equipment was quite small therefore only small simple parts with less density could be produced.

Today standard equipment is available ranging from $1\frac{1}{2}$ to 1500 tons depending upon the design and type of equipment. Refinements in design and utilization of better and stronger materials have greatly improved the rigidity and accuracy of current equipment. Hydraulic presses run much higher in tonnage capacity than mechanical presses and consequently the production rate decreases. However, the production rates of hydraulic presses have advanced considerably in the past few years because of the design improvements in the hydraulic circuits and mechanisms.

"Modern powder metallurgy, with its broad complexity of powder-metal part design, has created the need for presses to suit individual part compacting requirements. The machinery manufacturers serving the industry have developed quite a range of presses for the specific purpose of producing these complex, high density parts."[1]

The majority of P/M parts are compacted by mechanical means. Mechanical presses, in general, are used for making parts in the lower pressure range because their speed exceeds those of hydraulic presses in most cases. The two basic categories of current P/M compacting presses are mechanical and hydraulic. The main difference between the two are the mechanism for providing the source

[1]Reprinted by special permission from American Society of Tool and Manufacturing Engineers from Paper No. 105 titled "Presses for Powder Metallurgy" by James J. Kux, Copyright 1958.

of energy to operate the compacting tools (dies and punches). Since several designs or types of presses use both hydraulics and mechanics, some overlapping of the two categories occurs. These types are referred to as mechanical-hydraulic presses.

Compacting presses can be further classified into single-motion, double-motion, or multiple-motion types. The motions determine the type of punch (single or double) or number of punches that the press can actuate either simultaneously or sequentially.

The single-motion press applies pressure to the confined powder from one direction, usually the top punch. The bottom punch and die are stationary. It can also include a core rod to form through holes in the direction of pressing. The motion of the press causes the upper punch to exert pressure on the metal powder as it enters the die. The bottom punch remains stationary. The upper punch forms the top surface and the lower punch forms the bottom surface (Figure #47). The die forms the outer contour of the P/M part. This is also true for dual motion and multiple motion presses. The ejection cycle can be accomplished by the die remaining stationary while the lower punch raises the part from the die or the lower punch can remain stationary while the die is lowered from the part. Either of these two methods can be employed for both simple-motion and double-motion presses. Single-motion presses can be either of mechanical, hydraulic, or mechanical-hydraulic design.

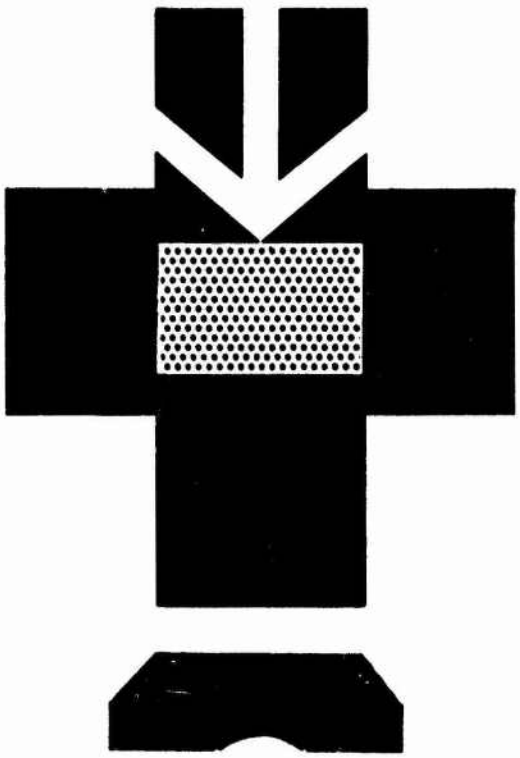


Figure # 47
Courtesy of F. J. Stokes Co.
Division of Pennsalt Chemicals
Corporation. Bull. No. 817

The double-motion press applies pressure to the metal powder in the die from opposite directions equally and simultaneously (Figure # 48). The double-motion press can be of the following two types:

Opposed Ram Design
Floating Die Design

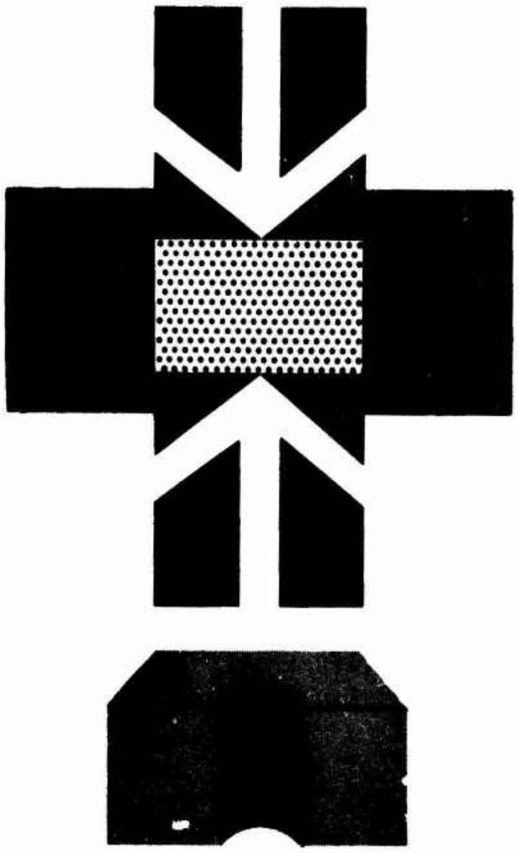


Figure #48
Courtesy of F. J. Stokes Co.
Division of Pennsalt Chemicals
Corporation. Bull. No. 817

The opposed ram type exerts equal amounts of pressure simultaneously upon the compact by the upper and lower punches to obtain as uniform a density throughout the part as is possible. The stroke of the upper and lower punches can be adjusted. The neutral axis of a part pressed by the opposed ram type of double-motion press is at the midpoint of the compact between the faces of the upper and lower punches. The optimum condition for producing parts of uniform density by conventional pressing equipment is for the neutral axis to be in the exact center between the faces of the punches. Double-motion opposed ram type presses have adjustments to control compression, ejection height, and powder fill. Stationary or movable core rods can be used for producing vertical holes in the P/M parts. These presses can be either of mechanical, hydraulic, or mechanical-hydraulic design.

The double-motion-floating die type press also exerts pressure simultaneously from both the top and bottom. In the floating die type of double-motion press the die moves downward as the upper punch decends into the die cavity. The lower punch remains stationary during the pressing cycle. The floating die is supported or held in its top position by a force absorbing mechanism. The floating die movement relative to the stationary lower punch creates simultaneous pressure from the top and bottom punches. The neutral axis in this type press will be below the midpoint of the pressed part. The density would not be uniform from both top and bottom of the pressed P/M part. To overcome this condition the press is designed with a compensating force to counteract the supporting force of the floating die. This compensating force will cause the die to move downward as the upper punch is forced into the die cavity. Parts produced by the floating die double-motion press are equal in density from both the top and bottom of the compact. The ejection cycle is accomplished in either of the same two ways as mentioned for the single-motion press.

The multiple-motion press is similar in principle and operates similar to the double-motion press. Whereas the double-motion press is used to press parts of one level the multiple-motion is used to press parts of more than one level. It operates on both the opposed ram principle or the floating-die principle and the comments referred to in the double-motion types also apply to the multiple-motion types. Multiple-motion presses utilizes two or more punches for both the top and bottom actuating surfaces (Figure #49). In other words a multiple-motion press is one that has two or more motions in either the top punches, bottom punches, or both. A movable core rod is also utilized for producing holes in the part in the direction of pressing. The lower punches can be adjusted separately and made to operate independently of each other. In the pressing cycle this will permit the size and density of each level of the compact to be controlled. The ejection cycles for both types of multiple-motion presses are identical to the double-motion types except that the punches work in unison during the ejection cycle and not independently as can be the case in the pressing cycle.

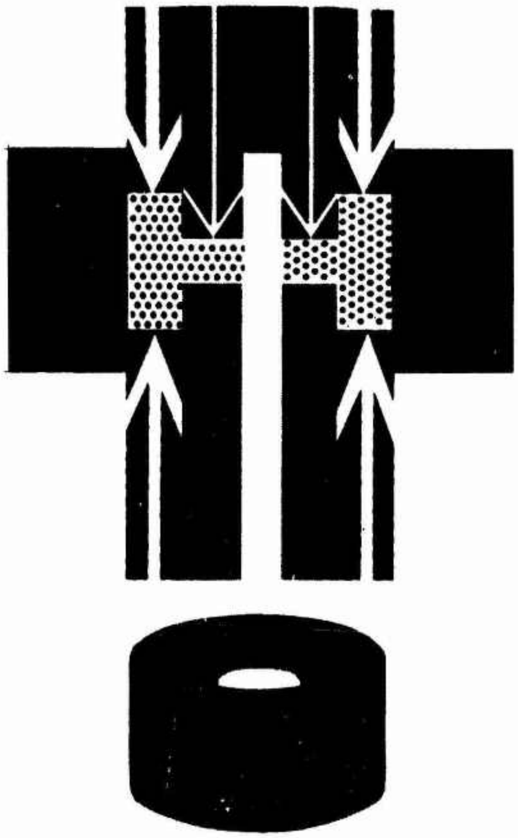


Figure #49
Courtesy of F. J. Stokes Co. Division of Pennsalt Chemicals Corporation. Bull. No. 817

(1) Single motion, double motion, and multiple motion presses are categorized as the following mechanical types according to their methods of applying pressure to the metal powders in the die cavity:

(a) Crank (eccentric driven) type
(b) Toggle type
(c) Cam actuated type
(d) Rotary type

(a) Crank presses are the simplest of the three types but are not as adjustable in regard to stroke and pressure control (Figure # 50). Their sequence of operations is simple and can only be varied by changing the timing cams which can require lengthy downtime. Presses of this type generally use simple tools to press simple parts; however, they can be adjusted and controlled to fabricate complex parts. They can actuate upper, lower, or both

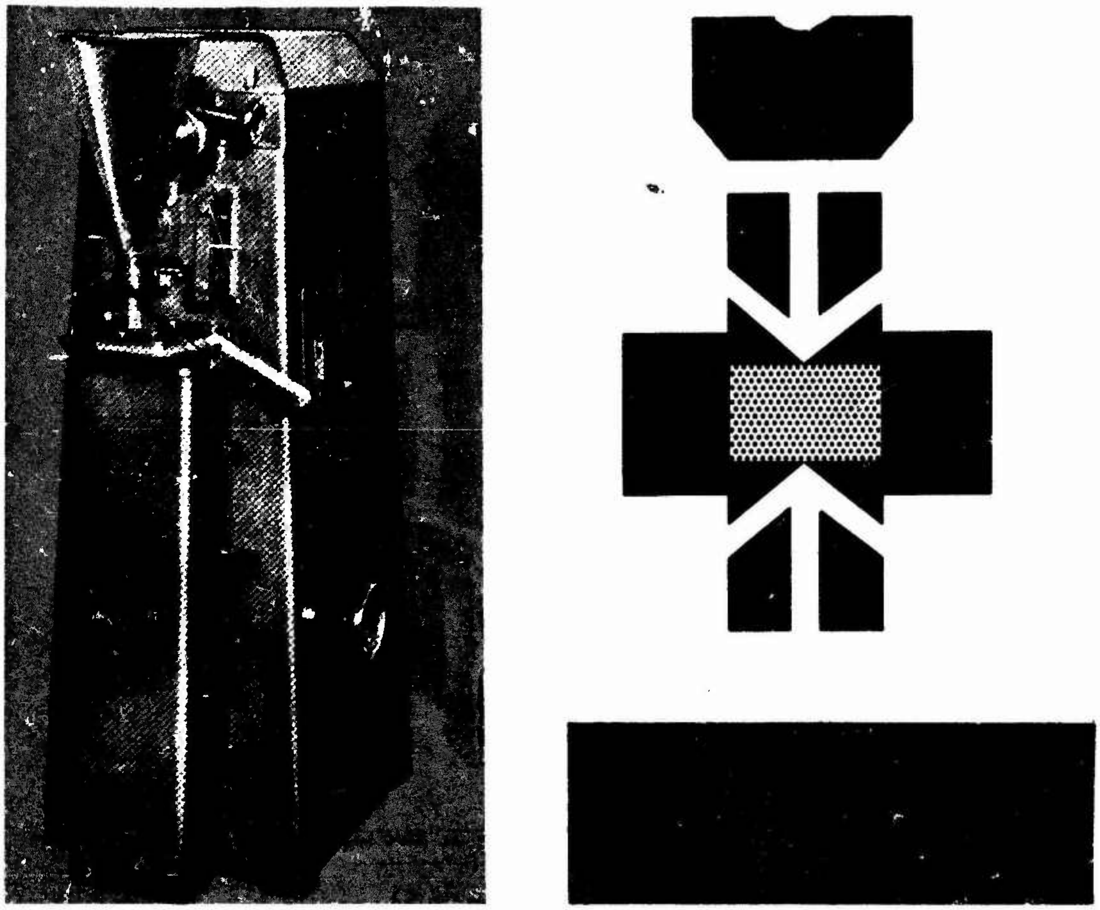


Figure #50
Courtesy of F. J. Stokes Company, Division of Pennsalt Chemicals Corporation, Bulletin 817-PM-10

punches in the pressing operation. Crank presses range from 4 tons to 50 tons. Parts generally no larger than three inches in the cross section can be pressed. Production rates are quite good and in some machines are as high as 75 parts per minute.

(b) Toggle presses for a given size and weight exert higher compacting pressures than either the crank or cam types. These presses are rigidly constructed and generally are referred to as the work horses of the powder pressing industry. These presses range in pressing capacity from 20 tons to 100 tons and die fills are as high as six (6) inches. Parts with diameters as large as eight (8) inches can be fabricated, but generally the range of cross section size is four (4) inches. The toggle press is similar to the crank press in that they both utilize simple-punch tooling,

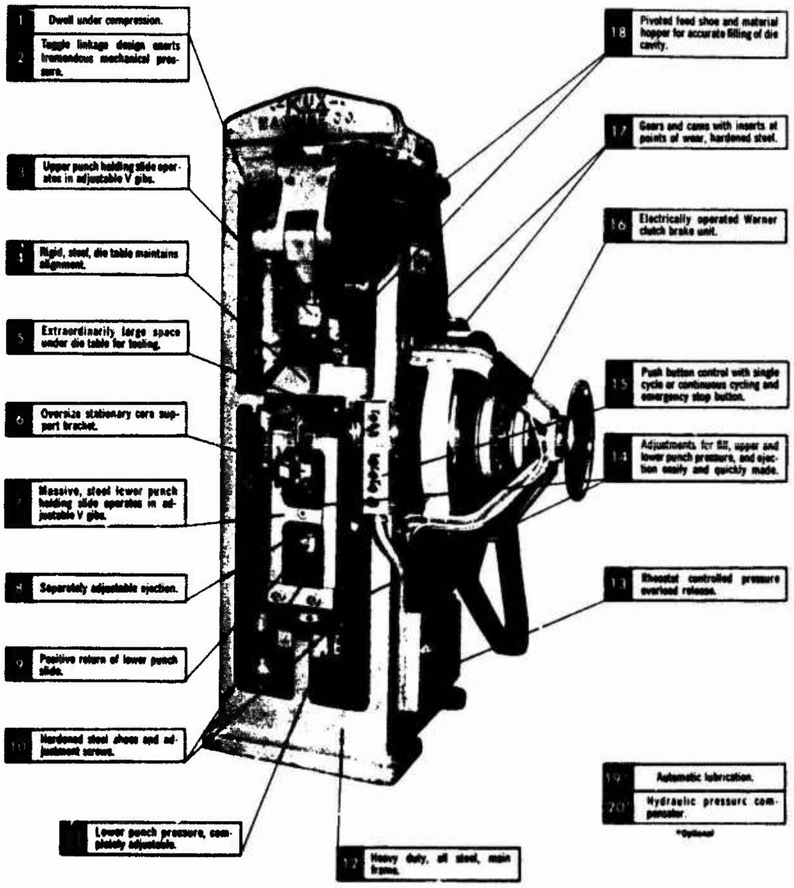


Figure # 51
Courtesy of Kux Machine Division, Wickes Corporation

but the toggle press has the advantage of applying far greater compacting pressure and has the advantage of a slow, smooth, squeezing action during the final pressing of the P/M part. This results in a compact of more uniform and higher density (Figure # 51). The toggle press is generally of the simple motion type.

(c) Cam operated presses are designed to produce complex and varying sectional-thickness P/M parts. The presses are designed with a mechanism for providing the die and punch motions as desired without relying upon springs and other type actuation for moving the tools. Cam operated presses are mostly of the multiple punch, multiple motion, design (Figure # 52). The multiple punches are independent of each other and can be adjusted for strike and pressure. The large press of the cam operated type

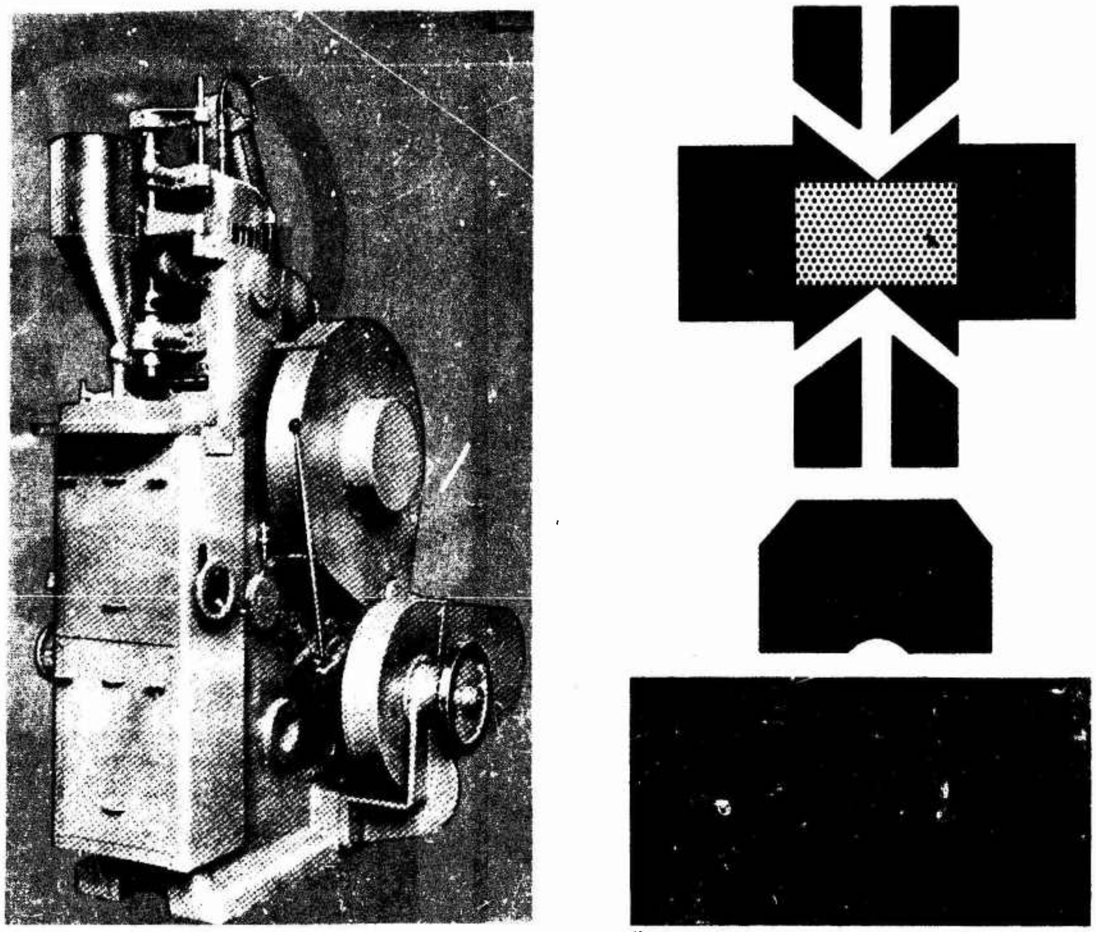


Figure #52
Courtesy of F. J. Stokes Company, Division of Pennsalt Chemicals Corporation, Bulletin 817-PM-7

ranges up to 100-ton capacity and can press sizes up to eight (8) inches in diameter.

Generally multiple punch machines are not considered as heavy-duty types because of the timing, flexibility, and intricacy required for the production of complex shapes.

(d) The rotary press is a high-production type for it utilizes numerous sets of tools (Figure # 53). This type of press is generally used for making small parts and coining small-size parts. A rotating turret carries the set of tools with cams actuating the punches.

Although the rotary press is a high-production tool, it does possess quite a few limitations. These include inflexible timing,

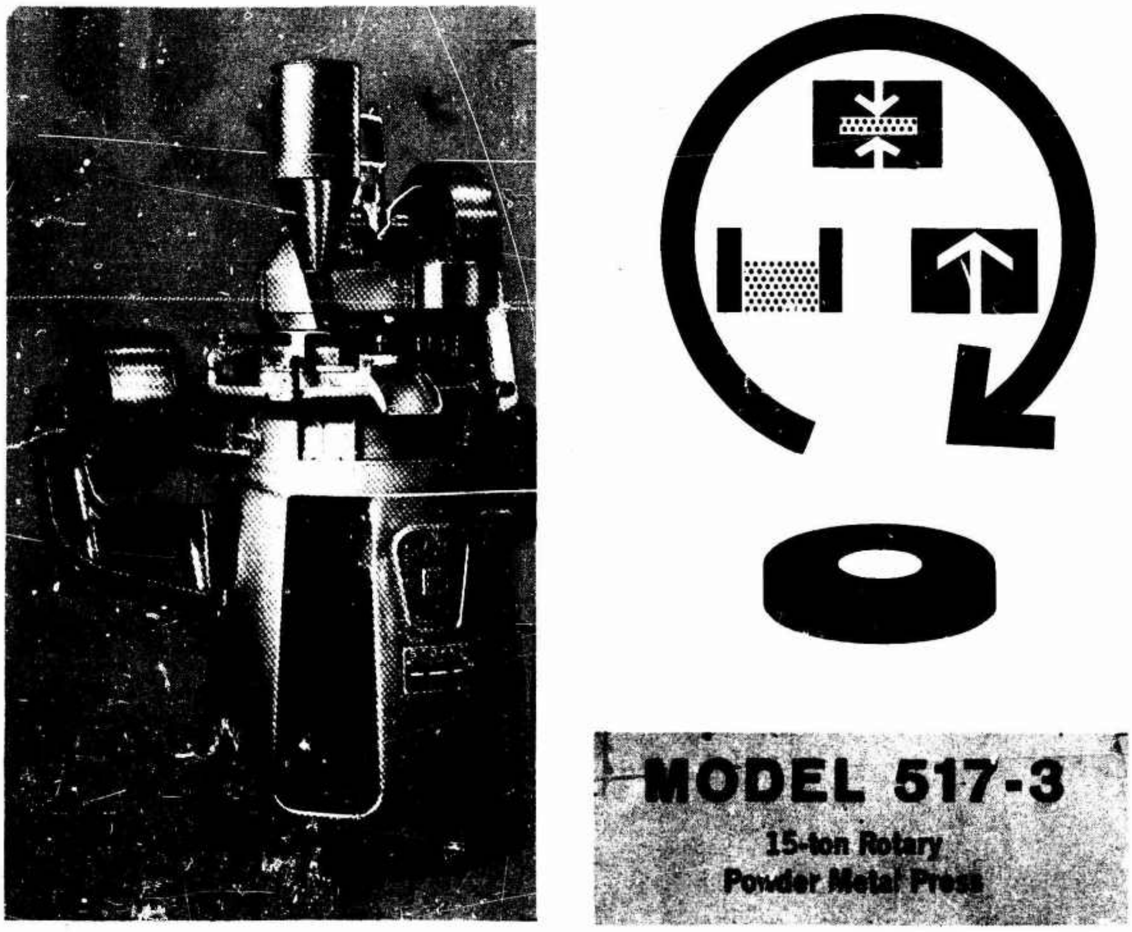


Figure # 53
Courtesy of F. J. Stokes Company, Division of Pennsalt Chemicals Corporation, Bulletin 817-PM-18

use of simple punch design, and low compacting pressure. Rotary presses, because of the above design disadvantages, are limited as a production tool because of their low compacting pressure and ability to press only simple shapes.

(2) Mechanical-hydraulic or pneumatic presses provides the high-speed automatic operation of a mechanical press and higher compacting pressure of the purely mechanical type and possess the uniform pressure of a pure hydraulic or pneumatic type press. Presses of this type too are commercially available up to 500 tons capacity (Figure #54). These machines generally utilize a mechanical drive system for actuating the punches and a hydraulic drive system for the lower punches during the pressing cycles. Other designs utilize mechanical drive mechanisms for both the upper and lower punches and the hydraulic mechanisms are used for secondary operations such as bringing the die and lower punches in the fill position. Actually these machines are more mechanical actuating types than either hydraulically or pneumatically. These machines are capable of pressing multiple level parts because most utilize multiple-motion tooling.

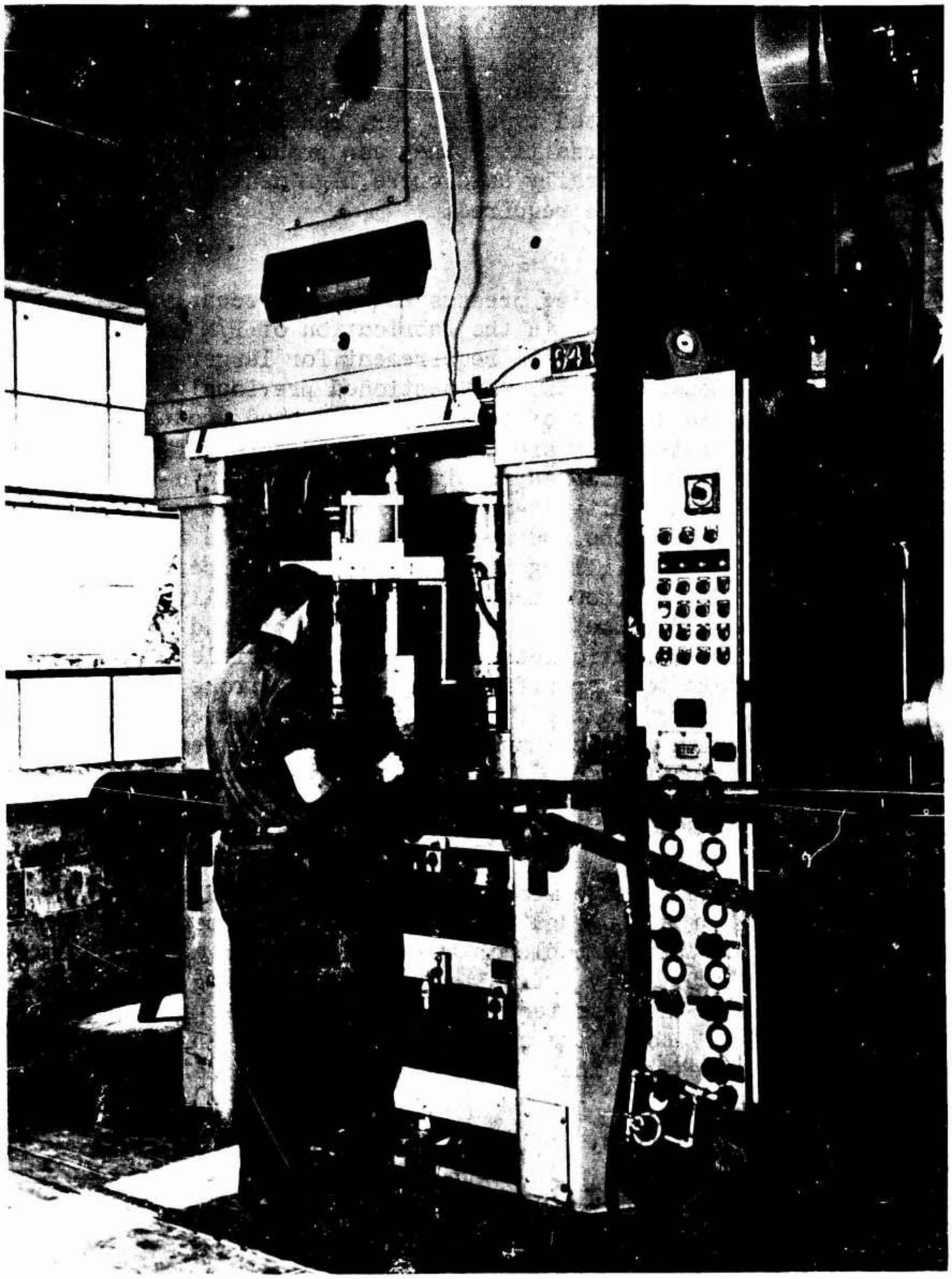


Figure #54
View of a compacting press, 400-ton multi-action mechanical press used in molding powder parts.

Courtesy of the Keystone Carbon Company

They can produce much larger parts than the lower capacity press and sizes ranging up to twelve (12) inches in diameter are not uncommon. Other than hydraulic types, these machines have the highest pressing capacity utilizing mechanical drive systems. Very intricate parts with unusual mechanical properties can be pressed by these sophisticated types at very reasonable production rates. Because of their versatility they can produce from small to large shapes but are generally used where high density and part-size over four inches are required.

(3) Hydraulic presses have only recently been utilized as pressing equipment in the fabrication of P/M parts. This has been brought about by the requirement for larger-size parts and very high-density parts. As mentioned previously, hydraulic equipment today is capable of providing very good production rates and because of this, they are being utilized more as a production tool. The presses are designed as simple-motion, single-punch as well as multiple-punch, multiple-motion. These presses range in sizes from 50 tons to 1500 tons and can be fully automatic in operation except for occasionally filling the powder supply hopper. Besides being designed for continous production, they are fully hydraulically controlled. Because in most cases the upper and lower punches are actuated by hydraulic mechanisms, it is possible to adjust the compacting tools to a specified pressure and stroke to apply the exact pressure desired to the P/M part being fabricated. Fully hydraulically operated presses have the most built-in versatility. Satisfactory production speed has been achieved through the utilization of adequate pumps and horsepower.

"The high tonnage mechanical as well as hydraulic presses are both used for sizing and coining, with either manual placement of the part on the die table or through use of an automatic hopper feed device."[1] Fully hydraulic presses provide greater tonnage, more safety, and less tendency to fracture the green compact upon ejection, due to the smoother, slower, and more positive application of pressure that these mechanisms are characteristically noted for.

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[1] Reprinted by special permission from American Society of Tool and Manufacturing Engineers from Paper No. 105 titled "Presses for Powder Metallurgy" by James J. Kux, C , right 1958.

f. Sintering:

(1) Sintering Mechanism
(2) Sintering Atmospheres
(3) Sintering Furnaces

(1) Sintering is the operation of powder metallurgy which follows cold pressing where the compacts are subjected to elevated temperatures in a controlled atmosphere furnace. It is probably the most important operation of the P/M process because the sintering parameters must be balanced if the compact is to possess the mechanical properties and physical characteristics that were originally designed for in the preparation of the green compact. The process itself is a complicated heat-treating operation for it not only includes most of the well-known problems involved in the heat-treatment of solid metals but also additional problems that are peculiar only to the sintering operation. The process is based on the bonding or atomic diffusion between adjacent particles of powder to form a coherent part. At sufficiently high temperatures the atoms in the surface layer become so mobile that they enlarge the contact area and group into one of two different lattices. Usually one lattice grows at the expense of the other and the diffusion is more pronounced as sintering temperature and time are increased. Time cycles and the temperature of the furnace are determined by the composition of the powders involved and the mechanical properties desired in the sintered part. For a more detailed treatise on the sintering mechanism the reader is referred to W. D. Jones' Fundamental Principals of Powder Metallurgy, London Publishers Ltd.

(2) Protective atmospheres are essential to the successful sintering of compacted metal powders. The object of such an atmosphere is to protect the powders from oxidation which would prevent the successful fusing together of the metal particles and reduce any oxides that might be present on the surface of the powders when they are pressed. The porosity of metal powdered parts presents a large amount of surface area that must be protected against chemical reactions (mainly oxidation) that are not encountered in the ordinary heat-treating of solid metals and alloys. On the other hand, atmosphere protection, porosity, and non-metallic inclusions permit the use of more drastic temperatures in a sintering operation than is possible in conventional heat-treatment operations. The protective atmosphere prevents oxidizing and scale on the surface of the P/M part while the pores and inclusions of the parts inhibit grain growth.

"Reducing atmospheres are therefore generally used. Vacuum sintering is costly and used only on a small scale in very special "cases that require it, or for research purposes. An inert atmosphere cannot reduce oxides or surface films that may be present on the pressed powders as they enter the furnace, nor can it burn up and eliminate air carried into the furnace in the porous compact or through the door when charging a load. Furthermore, an inert atmosphere free from traces of oxygen, water vapor and other undesirable constituents is very costly. For these reasons, inert atmospheres are not used commercially in powder metallurgy."[1]

The selection of the atmosphere depends upon the material (powder) to be sintered (for example, pure iron powder will oxidize in an atmosphere suitable for sintering copper), the initial cost of the atmosphere generator, and the operating cost of the generator.

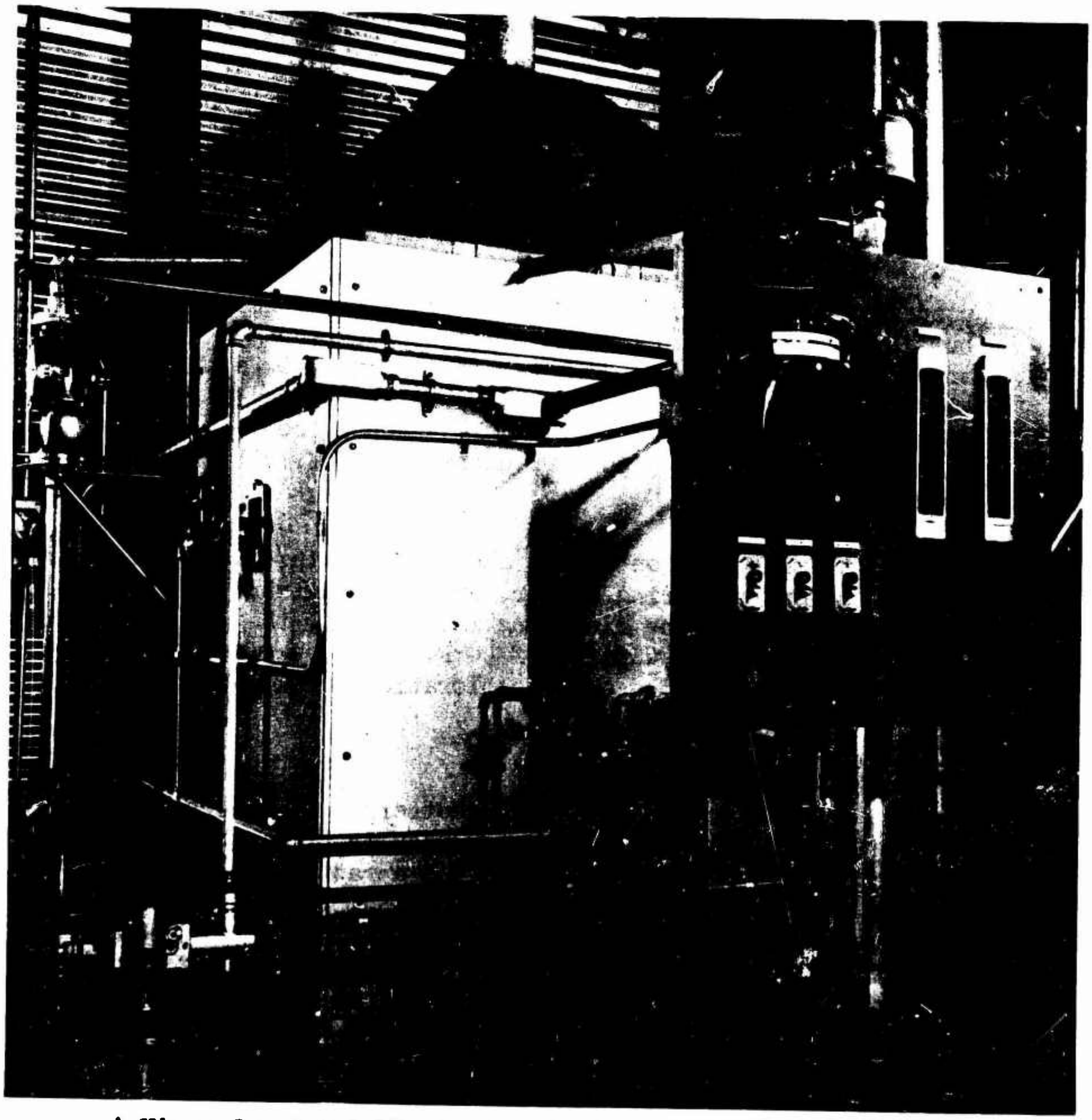
Following are some of the most commercially used sintering atmospheres (reducing types):

1. Hydrogen (pure)
2. Cracked Ammonia (Anhydrous)
3. Commercial or Natural Cracked Gas
   a. Exothermic gas
   b. Endothermic gas

1. Hydrogen. A common atmosphere used for the protection of parts and reduction of oxides is hydrogen. "Pure, dry hydrogen is an all-purpose sintering atmosphere. The high cost of the pure hydrogen atmosphere limits its commercial use to items which really require it. Pure, dry hydrogen must be used for sintering tungsten carbides, tantalum carbides, molybdenum, other refractory metals, stainless steels, or other alloy powders containing chromium (over 1%) or high in aluminum. Chromium will form an oxide in hydrogen if the dew point of the gas is above -20°F. (0.05% water vapor). It should be remembered that hydrogen will decarburize iron or steel powder. In order to keep hydrogen dry in the furnace, small muffle types are generally used."[1] Molybdenum heating elements are generally employed in hydrogen atmosphere furnaces.

2. Cracked Ammonia (Anhydrous). "In sintering operations where a high-hydrogen atmosphere is required, it is economically advantageous to produce it by cracking ammonia (anhydrous). An atmosphere containing 75% H_2 and 25% N_2 (by volume) is produced by passing the raw ammonia over a heated catalyst. Since no air is used in the cracking process, the resulting hydrogen-nitrogen mixture is free from oxygen or water vapor. The dew point of the cracked gas

[1]Reprinted by special permission from the American Society for Metals from the article "Atmospheres for Sintering Furnaces" by N. K. Koebel, as published in the May 1957 issue of METAL PROGRESS, (C) 1957.



A View of a Specially Designed and Built Endo Gas Cracker.

Figure # 55
Courtesy of International Powder Metallurgy Co., Inc.

"measures from -40° - 60°F. (0.0188 to 0.0056% water vapor) and is considered 'bone dry'. A well-designed dissociator will pass a maximum of only 0.05% of NH_3 (undissociated ammonia) when operating at full-rated capacity.

"Operation of the dissociator is simple. When cylinder ammonia is used, the workman connects several 150-lb. cylinders to the supply manifold. One cylinder is drained while the others stand by. When ammonia arrives by tank car or truck, the necessity for changing cylinders is completely eliminated.

"One of the principal uses of dissociated ammonia atmosphere is for the sintering of brass compacts; it gives equally good results as pure hydrogen at a savings on cost."[1]

3.a. Commercial Gas (Exothermic). The cheapest atmosphere used for sintering the majority of metal parts is cracking (partially burning) commercial, natural, protane or butane gas with air. Such an exothermic atmosphere consists of 17% H_2 (max.), 10% CO (max.), 4% CO_2 (min.) and the balance N_2. The atmosphere is chiefly used as an economic one for sintering low-carbon iron (if decarburization is not important) powder, copper, bronze, silver and nickel powder.

If the sulphur content is above .08 grain/cu. ft. it has to be removed before sintering copper, bronze or silver. When using exothermic atmosphere for sintering iron powder, the gas is dried by refrigeration to a dew point of 40°F. The lower content of moisture is required to present discoloration or oxidation of the part when it cools from 900°F. to 500°F.

3.b. Commercial Gas (Endothermic). "The chief difference between the endothermic and the exothermic process is that external heat is used to heat the catalyst and a ratio rich in gas can therefore be cracked with no combustion taking place in the catalytic chamber. Since no combustion takes place as such, the normal products of combustion, carbon dioxide and water vapor which cause decarburization, can be eliminated or reduced to any desired percentage. Furthermore, the carbon potential of the atmosphere can be adjusted to be in equilibrium with any carbon content steel."[1]

The endothermic gas atmosphere is the most widely used by the P/M parts industry and is most conveniently produced by cracking natural gas or propane endothermically with air to a gas mixture

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[1] Reprinted by special permission from the American Society for Metals from the article "Atmospheres for Sintering Furnaces", by N. K. Koebel as published in the May 1957 issue of METAL PROGRESS, (C) 1957.

free of decarburizing constituents. The atmosphere is used where decarburization is important and an application where a controlled carbon potential must be used. The endothermic gas is the best all-purpose low-cost atmosphere for sintering production powder metal parts of iron, copper, bronze and brass as mentioned, and also of silver and nickel. Although the generator costs about twice as much as the exothermic generator, the atmosphere it produces is necessary for sintering medium and high-carbon iron powder without decarburization.

(3) Sintering furnaces used for the sintering of P/M parts are similar in construction to the familar copper brazing types. However, there are certain principals of design that must be incorporated into a sintering furnace that are not required in the brazing furnace.

The fundamental difference in principal between the two types is the manner in which the parts to be treated are brought up to temperature. Parts to be brazed can be brought up to temperature rapidly and held for the brazing material to melt and flow. Parts to be sintered must be controlled and preheated to eliminate or burn off lubricant before the sintering process is begun in the main chamber of the furnace. The parts are generally brought up to temperature at a slower and controlled rate of heating, and are then held for a definite period at the sintering temperature to obtain the desired mechanical properties and density. The first stage of the sintering furnace is the burn-off purge chamber which is required to expel the air, volatize the lubricants and binders entrapped in the pores of the P/M green compact before the part enters the sintering chamber of the furnace. This is important and required to reduce the contamination of the sintering atmosphere. Also if P/M parts are heated suddenly, the volatizing lubricants may rupture the part or affect its dimensions and prevent close tolerance control.

The essential principals in construction of a sintering furnace are:

a. gas-tight shell or muffle
b. purge or burn-off chamber
c. control rate of preheating
d. control height heat chamber (sintering)
e. cooling chamber (water jacketed)

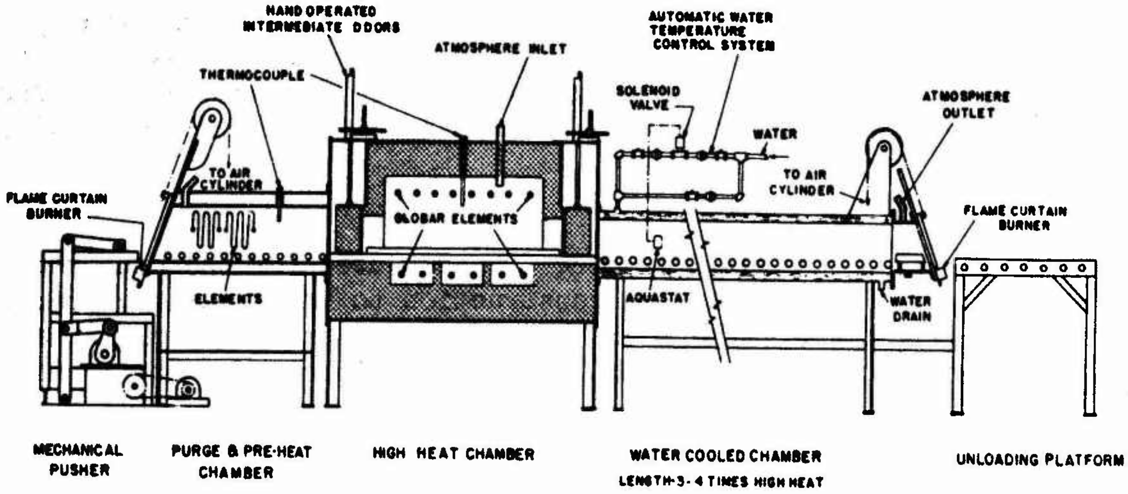

Figure #56
Courtesy of Lindberg Hevi Duty Division of Sola Basic Industries
(Lindberg Engineering Company Bull. 230A)

The purge or burn-off chamber is a very essential part of the sintering furnace (Figure # 56). As stated before, the lubricants such as zinc stearate, lithium stearate and other stearate acids are burned off because they are of no value in the sintering process and will interfere with good sintering if they are not properly expelled before the part reaches the high temperature portion of the sintering furnace (Figure # 56).

The high-heat chamber is the zone of the furnace where the sintering of the P/M part is accomplished. The chamber must be of the proper length to allow sufficient time at the desired temperature to obtain the desired density and strength. The chief cause of poor mechanical properties and density of a P/M part is that the part was not sintered at a sufficient temperature or was not held long enough at the proper temperature or a combination of both. Table I may serve as a guide in determining the proper sintering temperature and time for various materials.[1]

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[1]See Powder Metallurgy Equipment Manual, Part I, Sintering Furnaces and Atmospheres (C) 1963 by Metal Powder Industries Federation.

TABLE I

SINTERING TEMPERATURE AND TIME [1]

Material	Temperature, °F.	Time, Minutes
Bronze	1400 - 1600	10 - 20
Copper	1550 - 1650	30 - 45
Brass (80-20)	1550 - 1650	30 - 45
Iron	1850 - 2100	30 - 45
Nickel	1850 - 2100	30 - 45
Stainless Steel	2150 - 2300	30 - 45
Alnico Magnets	2200 - 2375	120 - 150
Tungsten Carbide	2600 - 2700	20 - 30

It can be seen from the table above that a part made from iron powder generally would require a sintering temperature of approximately 2000°F and a time of approximately 30 minutes. Therefore, it is important that the high-heat chamber of the sintering furnace is made to the proper length to insure that the charge (P/M parts) is brought to the desired temperature for the proper soak period.

" The cooling zone of the sintering furnace usually consists of a short insulated zone followed by a long water-jacketed cooling zone to cool the P/M parts to a temperature to prevent oxidation upon entering the room atmosphere (air). The short insulated cooling zone cools the part from the high-heat temperature to a lower temperature at a slower rate, to prevent thermal shocks. The temperature to which the P/M parts must be cooled before striking air depends on the material being sintered. Furnaces become quite long if cooling is to be provided below 300°F. The cooling rate is exceedingly slow at the low temperature range." [1]

There are three methods for conveying P/M parts through the sintering furnaces. They are:

a. Mesh-belt conveyer
b. Roller-hearth, continuous
c. Mechanical pusher type

a. "The mesh-belt conveyer furnace is one of the most commonly used sintering furnaces for continuous production of small,

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[1] Reprinted by special permission from Metal Powder Industries Federation from Powder Metallurgy Equipment Manual, Part I, Sintering Furnaces and Atmospheres, (C) 1963.

"light parts as copper, brass and iron."[1] An example of the mesh-belt type is shown in Figure #57 .

MESH BELT CONTINUOUS TYPE SINTERING FURNACES

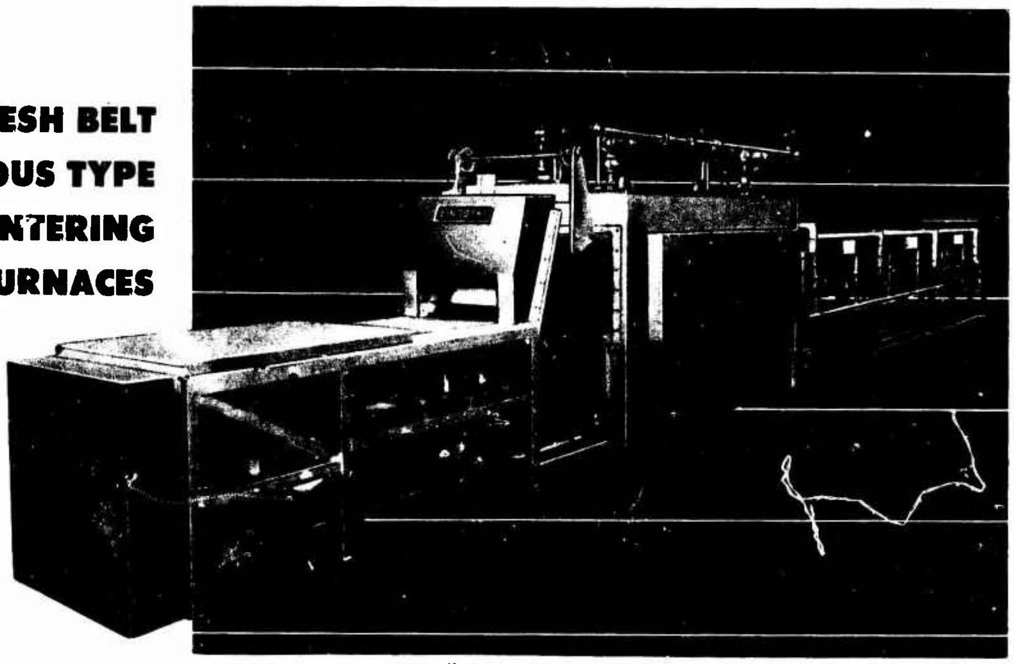


Figure # 57
Courtesy of Lindberg Hevi Duty Division of Sola Basic Industries
(Lindberg Engineering Company Bull. 230A)

b. "The roller-hearth continuous sintering furnace is similar to the conveyer-belt furnace except that the parts are loaded

ROLLER HEARTH CONTINUOUS TYPE SINTERING FURNACE

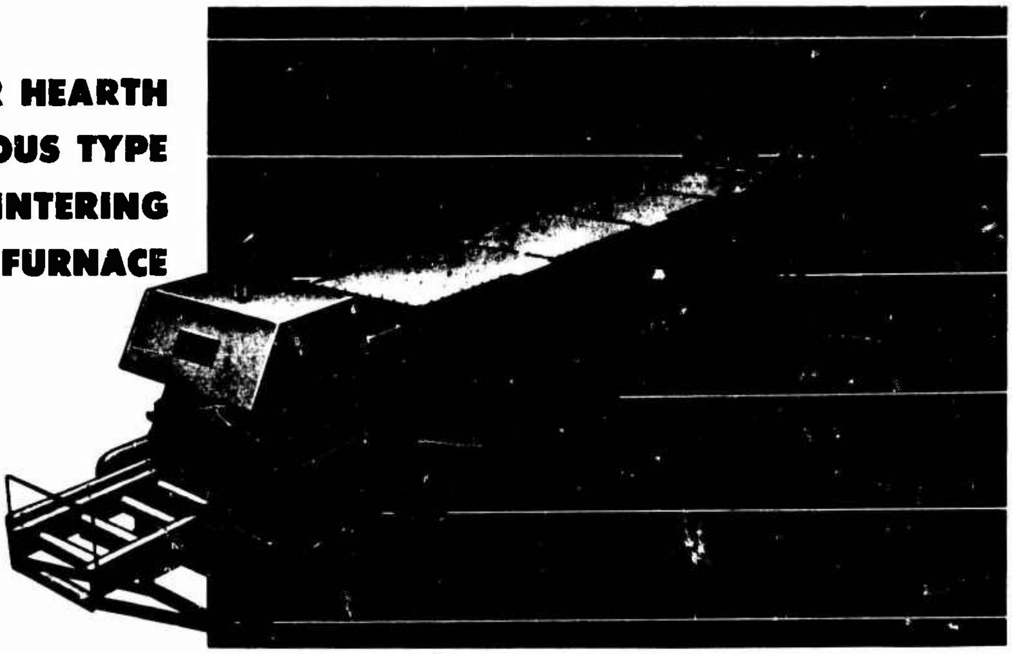
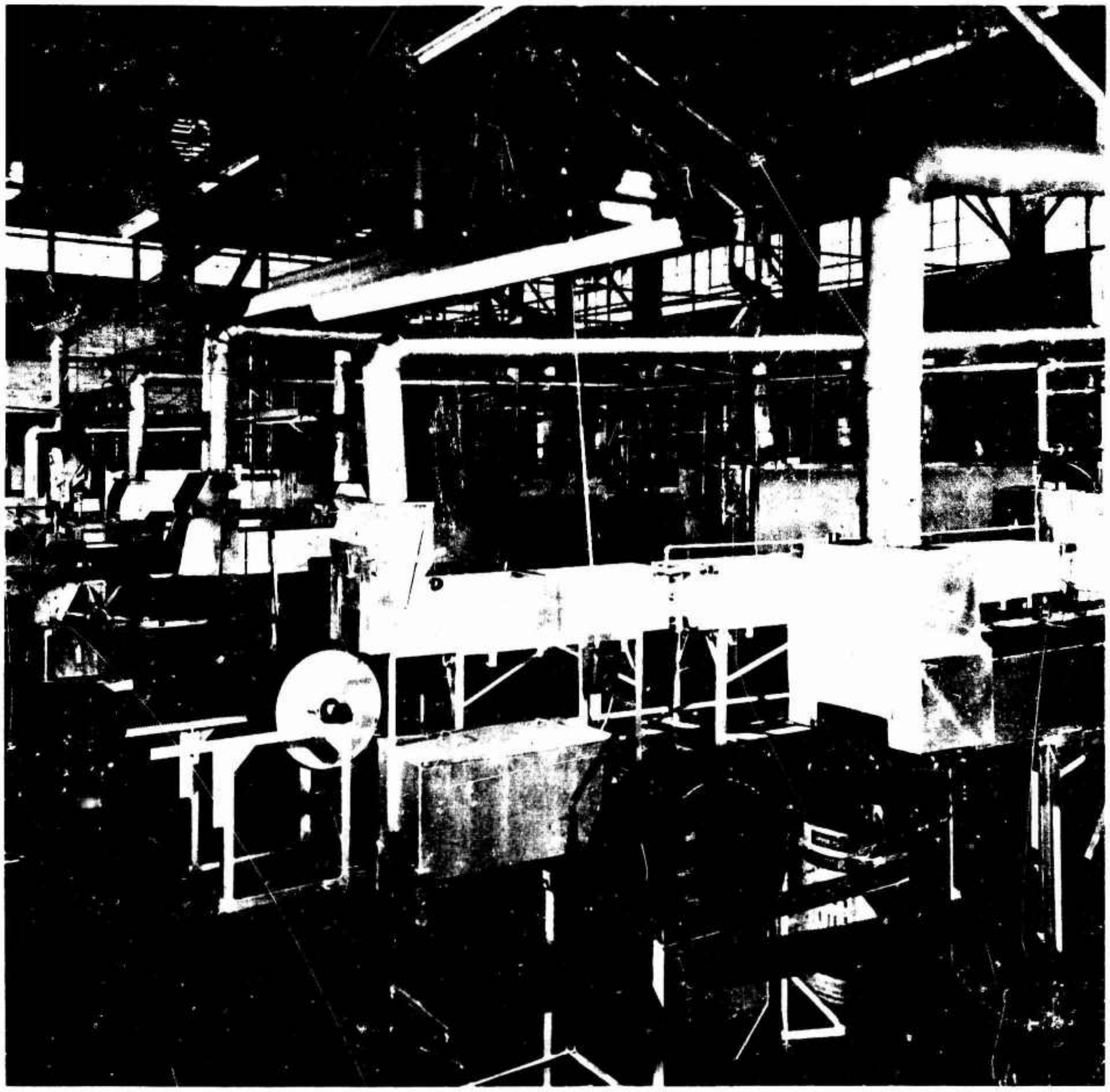


Figure # 58
Courtesy of Lindberg Hevi Duty Division of Sola Basic Industries
(Lindberg Engineering Company Bull. 230A)

[1] Reprinted by special permission from the American Society for Metals from the article "Furnaces for Sintering and Heat Treating Powder Metal Parts" by N. K. Koebel as published in the August 1957 issue of METAL PROGRESS, (C) 1957.

Sintering operation -- continuous belt-type furnace

Figure #59
Courtesy of Keystone Carbon Company



"ANOTHER VIEW OF THE SINTERING DEPARTMENT FROM A DIFFERENT ANGLE"

Figure #60
Courtesy of International Powder Metallurgy Co., Inc.

"into trays, and the trays are conveyed through the furnace. Roller-hearth furnaces are built to handle 500 lbs/hr and upward. They are useful not only for heavy parts, but also for high parts that require a large door, since the doors on a roller-hearth furnace are only opened when a tray of work is charged, whereas the doors on a mesh-belt furnace must be open continuously."[1] For an example of the roller-hearth type furnace, see Figure # 58.

c. "The mechanical pusher type furnace is also a continuous furnace in which the parts are loaded in trays, but the trays are mechanically pushed through the furnace instead of rolled."[1] An example of the mechanical pusher type is shown in Figure # 61.

MECHANICAL PUSHER TYPE CONTINUOUS SINTERING FURNACE

Figure # 61
Courtesy of Lindberg Hevi Duty Division of Sola Basic Industries
(Lindberg Engineering Company Bull. 230A)

"The mechanical pusher type furnace is particularly suited for sintering metal parts that are too heavy for the mesh-belt conveyer, yet the production rate does not warrant the roller-hearth furnace, and also for sintering at temperatures too high for an alloy belt or alloy roller."[1]

For a more comprehensive treatise on sintering furnaces, the reader is directed to the MPIF Equipment Manual, Part I, on Sintering Furnaces and Atmospheres.

[1]Reprinted by special permission from the American Society for Metals from the article "Furnaces for Sintering and Heat Treating Powder Metal Parts" by N. K. Koebel as published in the August 1957 issue of METAL PROGRESS, (C) 1957.

g. Tooling for Powder Metallurgy:

"Every part being considered for powder metallurgy must be analyzed thoroughly. The material specifications and pressure requirements must be determined in order to utilize the capabilities of the equipment. The motion necessary to press the P/M part must be determined to utilize those of the press and those that must be incorporated in the tooling." Good tooling is required as an economic element for a P/M part to be fabricated at a minimum of expense (Figure #62). For more detailed information on special tooling and tool design, the following is reproduced by special permission of the Metal Powder Industries Federation (MPIF) from their Powder Metallurgy Equipment Manual, Part II, Compacting Presses and Tooling, (C) 1965:

(1) The Die
(2) The Punch
(3) Tolerances and Clearances
(4) Finishes
(5) Punch and Die Adaptors
(6) Tools for Coining or Sizing

(1) "The Die. Most presses have large die openings. The main reasons are to provide ample space for adapting tools from one make or size of press to another, and to allow room for shrink rings when insert type dies are to be used.

"In checking die wall thickness, it is assumed that full hydraulic transmission of pressure is obtained, even though this is contrary to the no-side-flow theory. It is also assumed that the tensile stress in the die wall is distributed over an area corresponding to three times the thickness of the piece.

"Die inserts may be held in place by clamping or by shrink fits. The cases for shrink fits are preferably made of steels, which are not as hard as the usual die steels but are much tougher such as: chrome nickel tool steel. This steel is also used when the die insert is to be held in by screws as the toughness minimizes thread failures. When making shrink fits the usual interference between cold cases and steel inserts is about 0.0015 inch per inch of diameter. When carbide inserts are to be shrink fitted only about 0.0010 inch per inch should be allowed as the carbide will not 'give' as much as the steel, carbides having only about one-third the elastic modulus of steel.

"Die entrance edges should be beveled (about 15 from the vertical) or radiused. The bevel should be 1/32 inch deep, or less, depending

Carbide die cavity for powder metal gear also showing electrode used in EDM process on gear die. See new electrode and electrode after use denoting wear characteristics.

Figure #62
Courtesy of Keystone Carbon Company

"on the size and the thickness of the pressed pieces. This minimizes injury to the punch faces when setting up and operating. When possible, horizontal joints in or near the pressing area of the die wall should be avoided, since fine powder works into such joints and spreads the sections vertically in spite of all precautions regarding finish of mating surfaces and high retaining pressures.

"It is sometimes necessary to taper dies to aid in relieving expansion strains during ejection, otherwise horizontal laminations may appear in the compressed pieces.

"When taper is required it is usually not necessary to make full allowance for the complete expansion of the piece--an allowance of 2/3 of the expansion usually being sufficient. If the pressed piece after ejection is 0.006 inch larger than the die at the compression point, the taper can be made 0.004 inch.

"The useful life of the die depends on many factors; such as, the nature of the material being pressed, the unit pressure to be used, allowable tolerances in the finished compacts, material of construction and surface finish in the cavity. High chrome, high carbon steels are used for medium production requirements. The analysis usually runs about 12% chromium and 2% carbon, and both oil hardening and air hardening grades are available. The air hardening type is used for dies having sharp cornered cavities which might not stand the shock of oil quenching. These dies should be heat treated to obtain a hardness of 60-64 Rockwell C.

"Where volume of production is high or abrasive conditions are encountered, dies should be made of tungsten carbide with low cobalt percentage grades (Fig. # 63). When unusual shapes are encountered a number of carbide inserts can be fitted together with rings as shown in Figure # 64. This minimizes costly machining operations of solid dies."

(2) "<u>The Punch</u>. Punch steel requirements are very different from die steel requirements. Here toughness is an important factor. High carbon, high chrome steels are too brittle in most cases; 3% nickel, 75% chrome and carbon around 0.40 to 0.50%--the lower carbon used when sections are thin or chamfered edges are present. Special analysis in the A.I.S.I. 3400 class meet the above specifications. For less delicate parts the 320 class steel containing 1.75% nickel may be used.

CEMENTED CARBIDES FOR POWDER METALLURGY TOOLING
PROPERTIES AND TYPICAL APPLICATIONS

↑ SHOCK RESISTANT
↓ WEAR RESISTANT

NO.	% OF BINDER	HARDNESS, RA	TRANSVERSE RUPTURE, PSI	COMPRESSIVE STRENGTH, PSI	TOOL APPLICATIONS: CORES	TOOL APPLICATIONS: PUNCHES	TOOL APPLICATIONS: DIES
C-4	3%	92.3	177,000	800,000			Bearing Dies
C-9	6%	91.5	230,000	710,000	Simple Shapes Short Lengths		Straight Thru Dies—Simple Cavity Contour
C-10	6 to 9%	90.6	280,000	650,000		Ceramics-Ferrites High Polish & No Face Projections	
C-11	12 to 13%	89.7	310,000	600,000	Step Cores & Complex Contours	Ceramics-Ferrites Metal Powders Simple Face Projections	
C-12	14 to 15%	88.5	340,000	580,000	Step Cores & Vulnerable Contour		Complex Shapes Gear Forms Sectioned Dies
C-13	15 to 20%	87.4	375,000	550,000	All Cores within Physical Limits of Carbide	All within Physical Limits of Carbide	Multi-Level Dies Vulnerable Projections
C-14	20 to 30%	82 to 86	365,000	470,000			

All property data represents average for grade

Figure # 63

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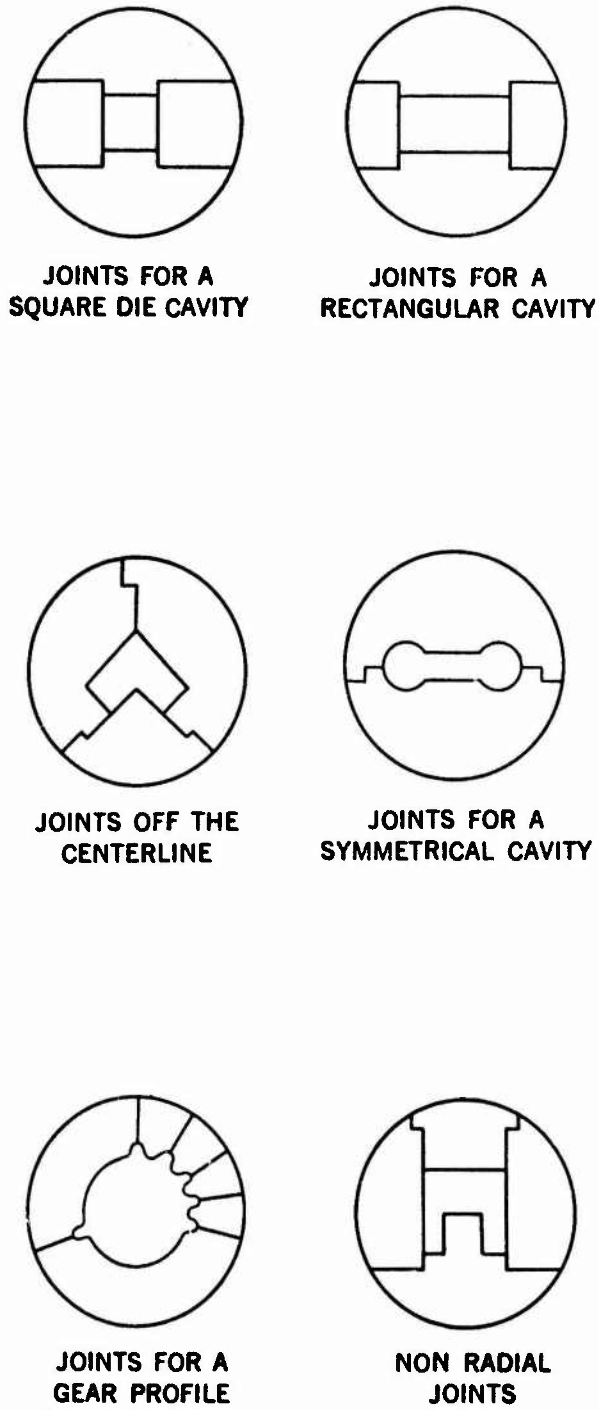


Figure 18

Figure #64

Reprinted by special permission from Metal Powder Industries Federation from Powder Metallurgy Equipment Manual, Part II, Compacting Presses and Tooling, (C) 1965.

A Small Portion of Tools in the Tool Crib

Figure #65
Courtesy of International Powder Metallurgy Co., Inc.

"When abrasion of punch face is high, punch inserts in chrome nickel steel holders can be used. The inserts can be made of high chrome steel with 1.5% carbon instead of 2% for simple shapes. If bevels and other stress concentrating details are present, the 5% chrome steels can be used. In those cases of multiple punch set-ups, where a punch may have to function partly as a die, the use of the 1.5% carbon high chrome steel is advisable.

"Carbide punches are sometimes used. The grade used should not be as brittle or as hard as that used for dies. The 9% or 12% cobalt grades are more durable. When using carbide tips the back up steel should be low chrome rather than high chrome tool steel to minimize mushrooming of punches under pressure after brazing.

"Punches and core rods are relieved 0.005 to 0.010 (0.12 to 0.24 mm) on the diameter and 0.0025 to 0.005 inches (0.006 to 0.12 mm) all around on all profiles to permit the escape of powder passing down beyond the punch faces. The actual close-fitting portions are made as short as is possible. Care must be taken, in considering the length of each fitting portion, to allow for relative motion between parts. Punches, particularly if they form chamfers, tend to chip at the edges, and may require regrinding several times in their useful lives. Some allowance must be made for this on the assumption that each regrind removes at least the length of the chamfer.

"Core rods are used to form blind or shoulder holes. Consideration must be given to column loading and other tougher steels must be used in this application. The working length of a core rod should be held to a minimum.

"Carbide coating applied by 'flame plating' or reverse electrical discharge are often used on core rods for highly abrasive application."

(3) "Tolerances and Clearances. Punches should be made to fit the dies within a specified clearance and not made to tolerances. The tolerances should be on the die and core rod dimensions (and the mating parts fitted with suitable clearances). The finest fits are required for making bearings and bushings. Any slight variation in powder fill tends to push the core rod to one side taking up all the clearances in one direction and producing eccentric bushings. No amount of subsequent pressure in the sizing operation can entirely correct the original eccentricity. For bushings the diametral clearances are usually not over 0.0002 inch. Eccentricity of I.D. and O.D. of punches should not be over 0.0002 inch T. I. R. For other applications the clearances are generally more liberal 0.0005 to 0.001 inch on diametral dimensions.

"In the making of the punches themselves, concentricity of the punches and the punch shank or punch holder need not be held to high accuracy. Most presses include provisions for locating the punches concentric with the die so that alignment can be obtained. However, there is no provision for adjusting out-of-square and the squareness must be accurately maintained in the tools especially in close fitting dies for long pieces.

(4) "Finishes. Die cavities and core rod should be lapped or polished to a high finish after final grinding and the last polishing or lapping should be parallel to the axis of the tools. The microinch finish should be 5 or better. When surface finish can not be readily checked with a profilometer, visual check for 'mirror' finish by an experienced tool maker is satisfactory. A well polished surface should have the same characteristics as a glass surface.

"Punch faces and punch 'lands' should have the same surface finish as the die cavities, and the final polish on the punch lands should be parallel to the punch axis. Punches and dies with poor surface finish wear out of tolerances much faster than when properly finished, and may prevent the tooling elements from moving freely to their proper position."

(5) "Punch and Die Adaptors. With proper preliminary planning and ingenuity in adaptor design, large savings in tool cost and emergency scheduling can be made. By the use of proper adaptors the basic tool element can be held to a minimum size. Where a variety of presses are in operation it is advisable to provide punch and die adaptors so that tools from one press may be operated in other presses of different size or make.

"The adaptors should be made from steels having adequate structural and dimensional stability so as not to detract from the accuracy of basic tool elements."

(6)" Tools for Coining or Sizing. Pressed and sintered compacts coming from the sintering furnace may be off size either intentionally or unintentionally. Such parts can be repressed, sized or coined to increase the density to reshape or to correct dimensional variations.

"Repressing can occasionally be done in the same die or slightly different die in the same press, equipped with a part feeder instead of a powder feeder, or, for short runs the parts can be fed by hand.

"In many cases the tools are very similar to the forming tools and are made of similar or slightly harder materials. Sizing pressure may run 50% to 100% greater than forming pressures. The die and core rod are provided with a tapering lead-in to assist the entrance of the parts into the die. In some cases the core pin is an integral part of the upper punch, or it may be a separate upper punch, or the hollow punch may be spring mounted on the core rod pin.

"Another method, used chiefly in self-lubricating bearings, is to force the bearing into the die and then run a spherical burnishing tool through to size and refinish the inside diameter. Self-aligning bearings and other spherical parts require special treatment to remove the central flat left by the forming process. The spherical section of these parts is sized half in the upper punch, which comes down and meets the die but does not enter it. The upper punch has a thick wall to withstand the sizing pressures."

h. <u>Economics</u>:

The economic consideration of the powder metallurgy process as a competitive method of fabrication to other methods of fabrication such as casting, extrusion, forging, and machining is quite involved. A few guide lines have been established which tends to categorize the process as a method which is limited to large production quantities to realize cost savings in comparison to the other metal forming techniques. This is especially true where small parts are involved. But powder metallurgy as an economic competitive process should be considered for other reasons, in addition to the large volume of parts concept. Some of the other economic considerations of the process are:

(1) Manufacturing Cor iderations:

(a) High speed mass production techniques
(b) Lower tool and equipment cost
(c) Elimination of expensive equipment for performing secondary operations
(d) Utilization of costly floor space occupied by secondary operation machines
(e) Elimination of slow and costly machining and conventional forming methods
(f) Elimination of secondary operations for obtaining close tolerances and surface finish
(g) Elimination of costly scrap

(2) Design Considerations:

(a) Fewer subassemblies to produce finished components

(b) Intricate shapes that would be costly or difficult to form by other methods

(c) Multipart components fabricated into one-piece parts

(3) Product Improvement:

(a) Precision quality control

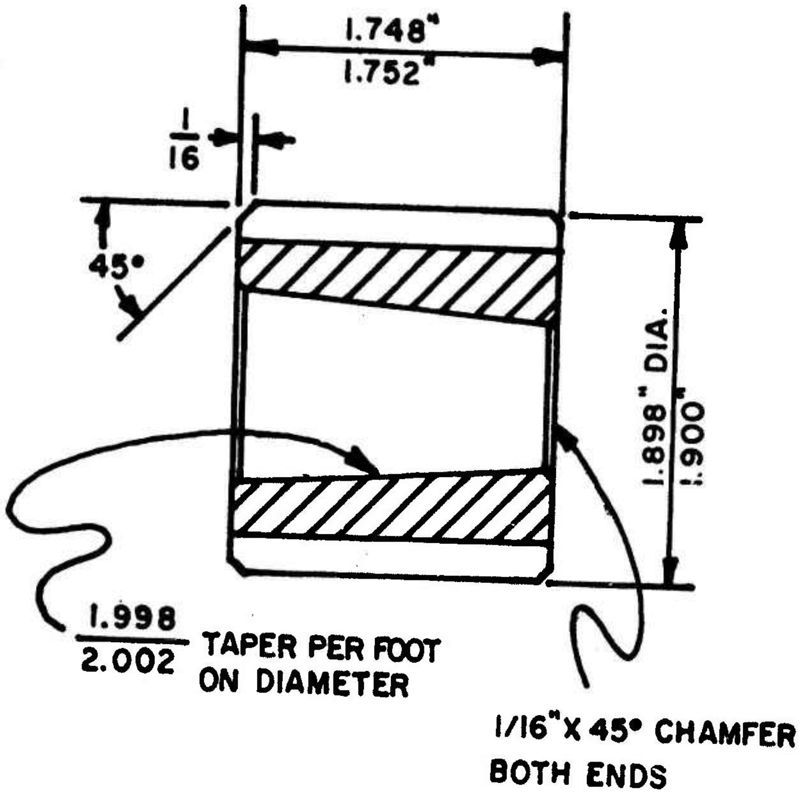
(b) Built-in (self) lubrication

(c) Taylor-made metals (alloys that cannot be produced by fusion metallurgy)

A majority of metal components or parts are fabricated from raw and wrought materials (mostly steel) not merely because the mechanical properties of the materials are required for the part, but because it is assumed that the raw and wrought materials are the cheapest for the functional purposes desired. The habit of using steel may lead designers and production engineers to specify mechanical properties in parts simply because the raw materials possess these characteristics, when they may not be required for the structural part. Designers and production engineers should determine exactly what mechanical properties such as strength ductility, hardness, etc. are required for the part especially when the powder metallurgy process is being considered as a competitive method of fabrication in order to gain the full advantage of the process.

Powder-ferrous and nonferrous metals are higher in cost than raw metals, and in most cases, the same is true for wrought metals. The ratio is usually two or three times as much for powdered metals in comparison to bar-stock metals. For some metal alloys, the ratio in cost is even higher. The powder metallurgy process compensates for the higher cost of powdered materials by using less material for forming a part, eliminating most secondary and finishing operations, and utilizing less machine time and man-hours for the fabrication of parts.

It would be more meaningful if cost figures to prove the economics of the P/M process over conventional methods for forming a part were presented, but this type of information was difficult to obtain since most P/M parts fabricators were unaware of the previous method and cost for the production of a part. In some cases the parts were designed to be fabricated especially by the P/M process. To convey the economical potential of the P/M process, specific examples and illustrations of P/M fabricated parts are presented in the following (Application) section.



CASE HISTORY

TITLE:	Pinion Gear
USE:	Textile Machinery
MATERIAL:	Wakefield Alloy 65 - 2 Cu, 4 Ni, .75 C, remainder Fe
PRESSING:	Double pressed
SINTERING:	Double sintered
PROCESS:	Material is pressed, presintered, repressed for higher density and sintered at the final temperature
SINTER. TEMP.:	2050°F
ATMOSPHERE:	Endothermic Gas
COINING:	Sized for accurate dimensional control
PHYS. PROP.:	UTS - 80,000 psi Elong - 1.6%/in Hardness - Rockwell B 90 Microhardness - B 95 - C 30 No subsequent heat treatment is required (Used as sintered)

COST:

P/M Process	$ 0.90
Previous Techniques	1.80
P/M Tooling (Informational) (2 Sets required)	1700.00/Set

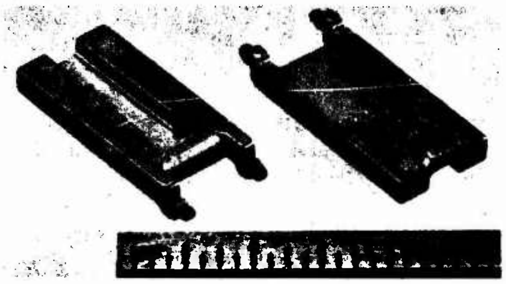
Courtesy of Wakefield Bearing Corporation

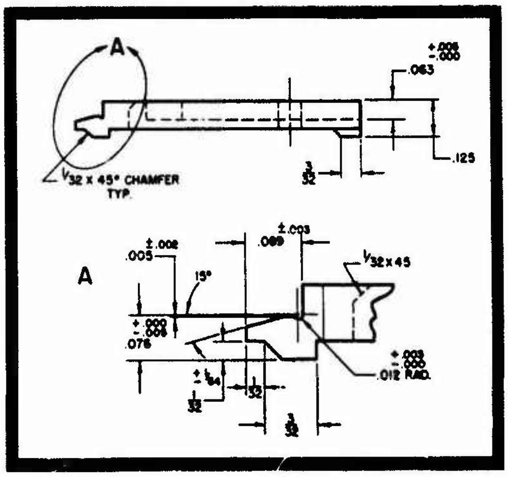
HEAT SHUNT (Printed Circuit Tool)
Prealloyed bronze, hard chrome plated

HOWARD NEEDHAM
North American Aviation
Fullerton, California

JOHN MIKITKA
Kwikset Powdered Metal Products
Anaheim, California

95% cost saving. Previously machined from bronze (cut off, milled, drilled, deburred and hard chrome plated). Excellent heat conductivity essential.



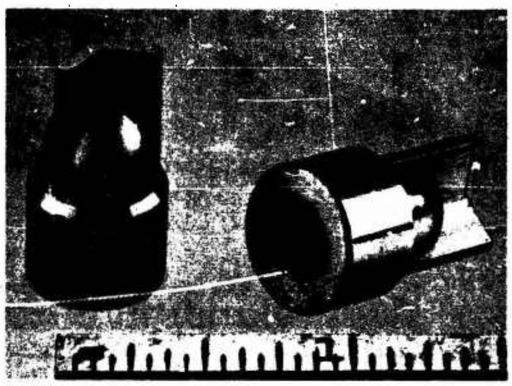


3-WAY VALVE PLUG
Nickel silver powder

MR. WESLEY MOLINE
Barber-Colman Company
Rockford, Illinois

MR. J. M. HILDABOLT
Metal Powder Products Co.
Logan, Ohio

47% cost saving providing shape and smooth, non-corrosive finish essential. Previous machined prototype required milled slots for guide fins which were silver soldered in place.

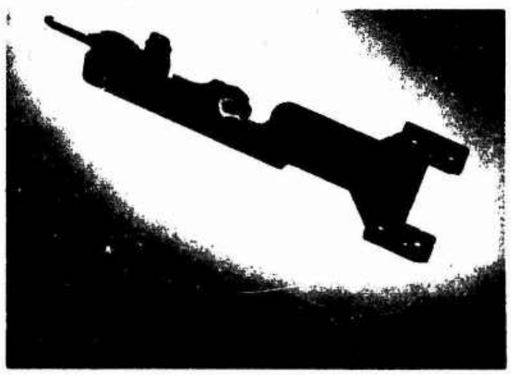


LEVER FOR FLOW METER
Nickel silver powder

MR. P. K. TRACY
MR. L. N. HATCH
MR. N. S. GRAVES
The Foxboro Co.
Foxboro, Massachusetts

MR. ALEXANDER L. ALVES
Engineered Plastics Inc.
Watertown, Connecticut

Cost saving 72%, with improved accuracy and corrosion resistance over original brass investment casting.

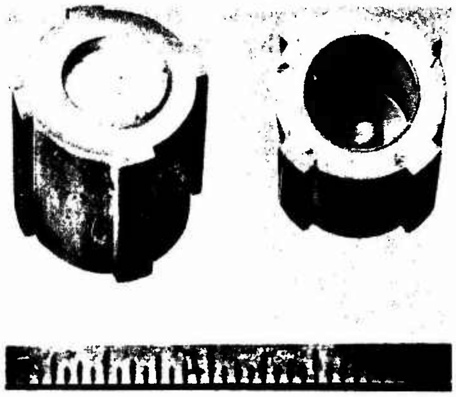


Courtesy of METAL POWDER PRESS

DISC HOLDER FOR REFRIGERATION SYSTEMS
Brass Powder

MR. PAUL BARTH
MR. TOM KEARNS
Mueller Brass Co.
Port Huron, Michigan

40% cost savings while providing precise tolerances and concentricity consistent from part to part. No scrap loss. Previously machined from extruded brass rod.



LONG & SHORT ARMS FOR MULTI-PURPOSE FLOAT VALVE
Brass Powder

MR. W. NAUGHTON
MR. B. HEINDRICKS
Robert Mfg. Corp.
Los Angeles, California

MR. JOHN MIKITKA
Kwikset Powdered Metal Products
Anaheim, California

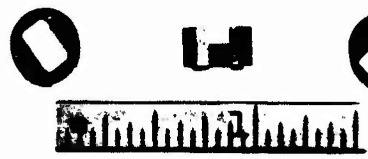
15% over-all cost savings. Improved design. Sharper teeth possible permit finer adjustment than original brass sand casting.

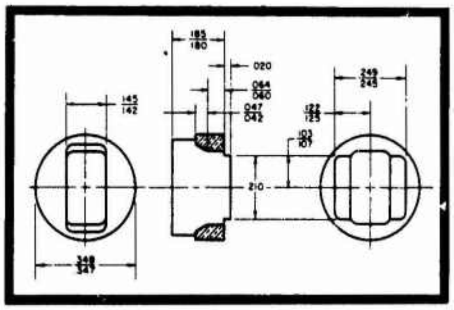
SLEEVE FOR TOGGLE SWITCH
Brass Powder

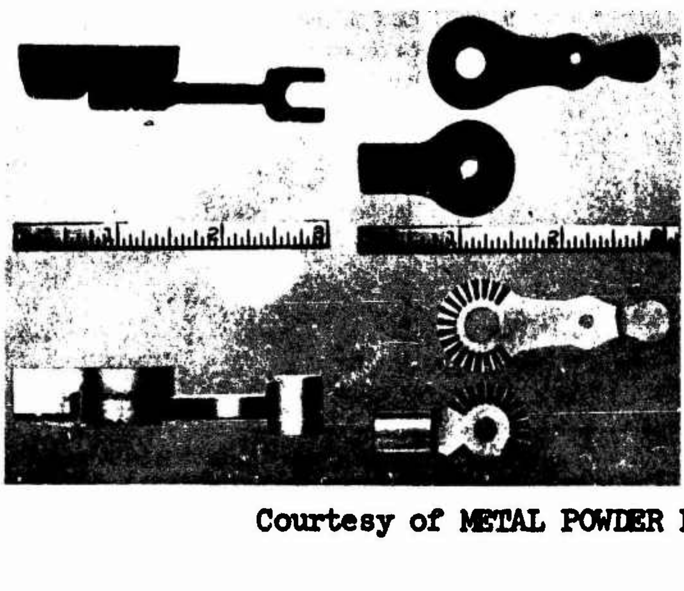
MR. P. F. HOHMANN
Microdot Incorporated
South Pasadena, California

MR. DONALD M. PAULLIN
Pacific Sintered Metals Co.
Los Angeles, California

93% cost savings. OD held ± .0005". Previously machined from brass rod (turn, broach, cut off, jig, mill, reverse, mill, deburr).







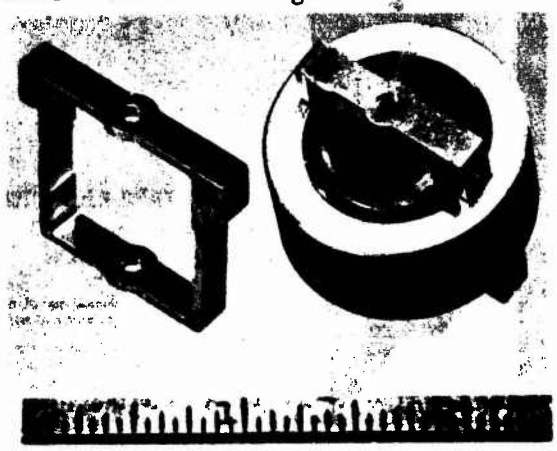
Courtesy of METAL POWDER PRESS

FRAME FOR CORE MAGNET
Brass Powder

MR. LAWRENCE R. BURK
General Meters Inc.
Grand Junction, Colo.

MR. R. A. BAGBY
Ferro Powdered Metals
Salem, Indiana

High structural strength essential. Most tolerances ± .001". New design.



LIFT KNOB
Brass Powder

MR. ROBERT E. PETERSON
Union Brass & Metal Mfg. Co.
St. Paul, Minnesota

MR. PHILIP V. TARR
Midwest Sintered Products Corp.
Chicago, Illinois

20% cost saving and equivalent finish of previous screw machine part. Crown buffed for easy plating.

Courtesy of METAL POWDER PRESS

INDUSTRY: **AUTOMOTIVE**

PART: Gears for pump in air conditioning unit.

MATERIAL: Sintered steel, oil impregnated.

FORMER METHOD: None. Designed for powdered metal.

ADVANTAGES: No machining or finishing. Close tolerances. Low cost.

INDUSTRY: **FRUIT PICKING**

PART: Sprocket.

MATERIAL: Sintered iron, copper infiltrated.

FORMER METHOD: Machined.

ADVANTAGES: No machining or finishing. High strength. Closer tolerances. Cost reduced 74%.

INDUSTRY: **ELECTRIC MOTOR**

PART: Self-aligning spherical bearing.

MATERIAL: Sintered bronze, oil impregnated.

FORMER METHOD: None. Designed for powdered metal.

ADVANTAGES: Double sphere, different diameters, without machining. Long life. Close tolerances. Self-lubricating.

INDUSTRY: **AUTOMOTIVE**

PART: Piston for shock absorber.

MATERIAL: Sintered steel.

FORMER METHOD: None. Designed for powdered metal.

ADVANTAGES: Uniformity. Close tolerances. No machining or finishing. Low cost.

INDUSTRY: **TRUCK SCOOTER**

PART: Door latch.

MATERIAL: Sintered iron, copper infiltrated.

FORMER METHOD: Casting

ADVANTAGES: No machining. High strength. Long life. Closer tolerances. Lower cost.

INDUSTRY: **WATER SPRINKLER**

PART: Gear box cover.

MATERIAL: Sintered brass.

FORMER METHOD: Casting.

ADVANTAGES: Better finish and appearance. No machining. Closer tolerances. Lower cost.

INDUSTRY: **ELECTRONIC**

PART: Rotor.

MATERIAL: Sintered magnetic iron.

FORMER METHOD: Machined.

ADVANTAGES: No machining or finishing. Maximum magnetic properties. Closer tolerances. Lower cost.

INDUSTRY: **WATER SPRINKLER**

PART: Segment gear.

MATERIAL: Sintered nickel silver.

FORMER METHOD: Casting.

ADVANTAGES: Closer tolerances. Lower cost. No machining or finishing.

INDUSTRY: **TAPE RECORDER**

PART: Housing bushing.

MATERIAL: Sintered bronze, oil impregnated.

FORMER METHOD: None. Designed for powdered metal.

ADVANTAGES: Self-lubricating. No machining. Low cost.

INDUSTRY: **LAWN MOWER**

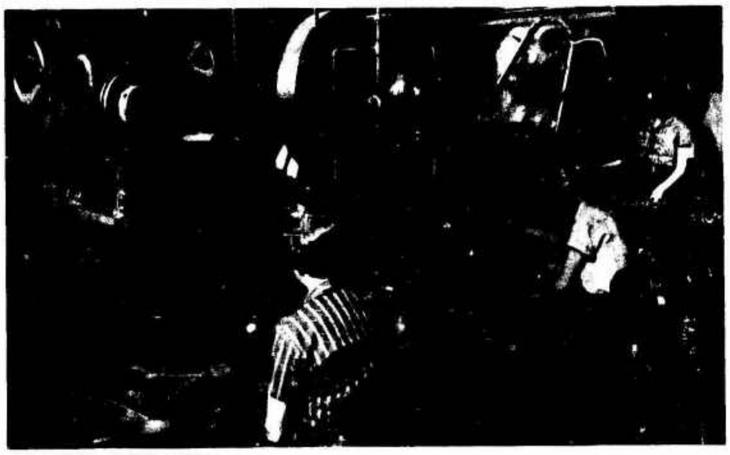
PART: Cam gear—starter

MATERIAL: Sintered iron, copper infiltrated.

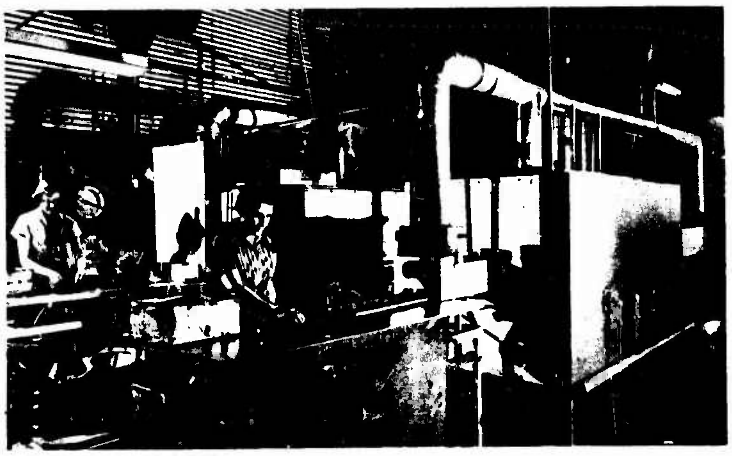
FORMER METHOD: Cut and machined.

ADVANTAGES: No machining or finishing. Closer tolerances. Lower costs. Uniformity.

Courtesy of Rocky Mountain Metals Division, Inc.



MOLDING OPERATION



SINTERING OPERATION

COINING OR SIZING OPERATION

POWDERED METAL ADVANTAGES

SAVE $
MACHINING COSTS

SAVE $
PRODUCTION COSTS

SAVE $
ASSEMBLY COSTS

SAVE $
DESIGNING AND TOOLING COSTS

SAVE $
SCRAP COSTS

SAVE $
INSPECTION COSTS

Courtesy of Rocky Mountain Metals Division, Inc.

Microscope Maker Looks to P/M Parts for Big Savings

The mysteries of the microscopic world can be easily brought into focus with this 10x and 20x "Student Stereo" microscope containing parts made by the powder metallurgy process.

In redesigning the instrument, the engineers at American Optical Company in Buffalo, N.Y. required an adjustable, economical slide mechanism to be corrosion resistant and to possess specific bearing characteristics. Powder metallurgy more than met these demands, and did so at one-third the cost of the former machined brass assembly!

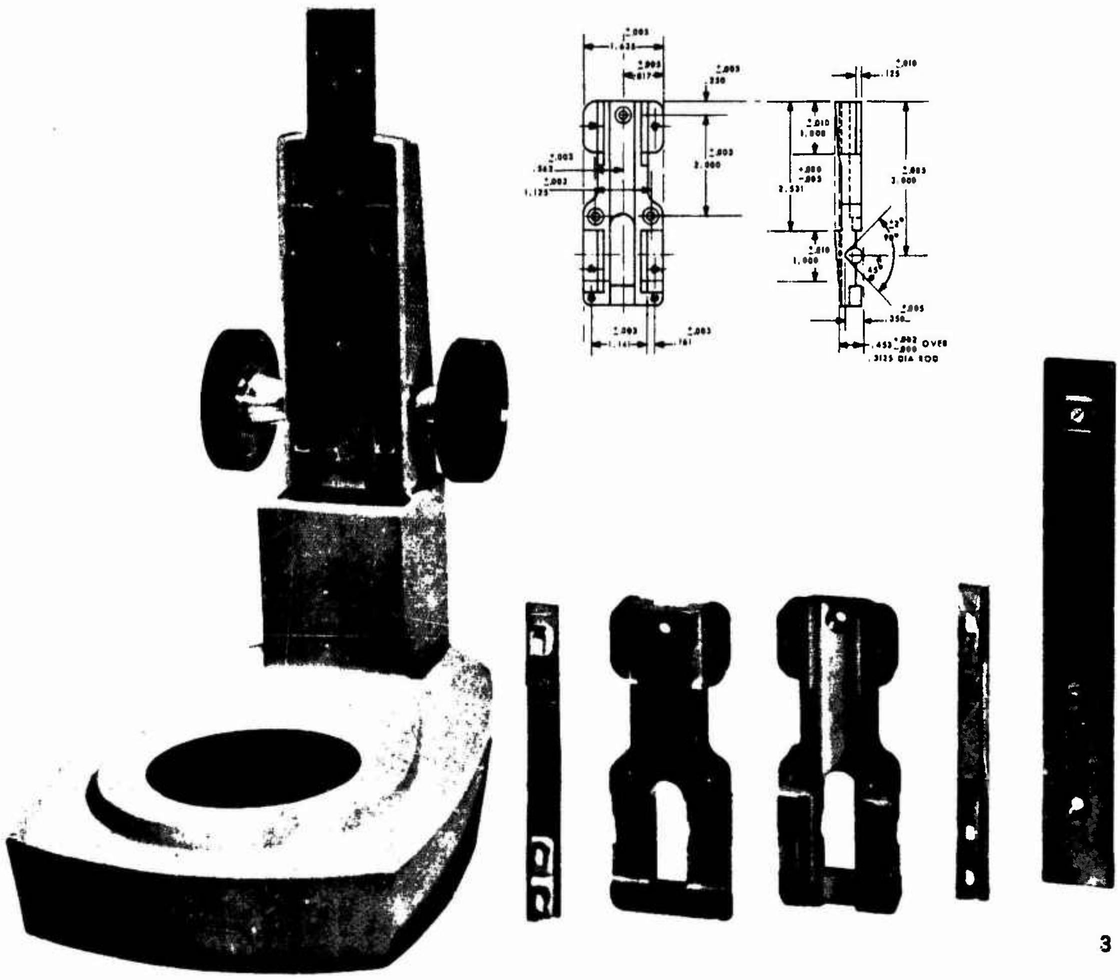
Parker White Metal Company of Fairview, Pa. uses two alloys of metal powder to produce the four parts. The slide frame is pressed from bronze while the gibs and rack are fabricated from brass.

This outstanding design permits easy adjustment of the slide mechanism and allows the gibs to be used without further machining operations. Bronze in the slide frame also serves as a bearing material for the pinion gear shaft.

Brass was chosen for the rack because of its combination of strength and ductility. The strength is required in the teeth and the ductility to allow for slight bending in the rack. This bending, in turn, allows greater tolerances between rack and pinion without impairing the function of the unit. Tolerance was increased to .004" maximum as a result.

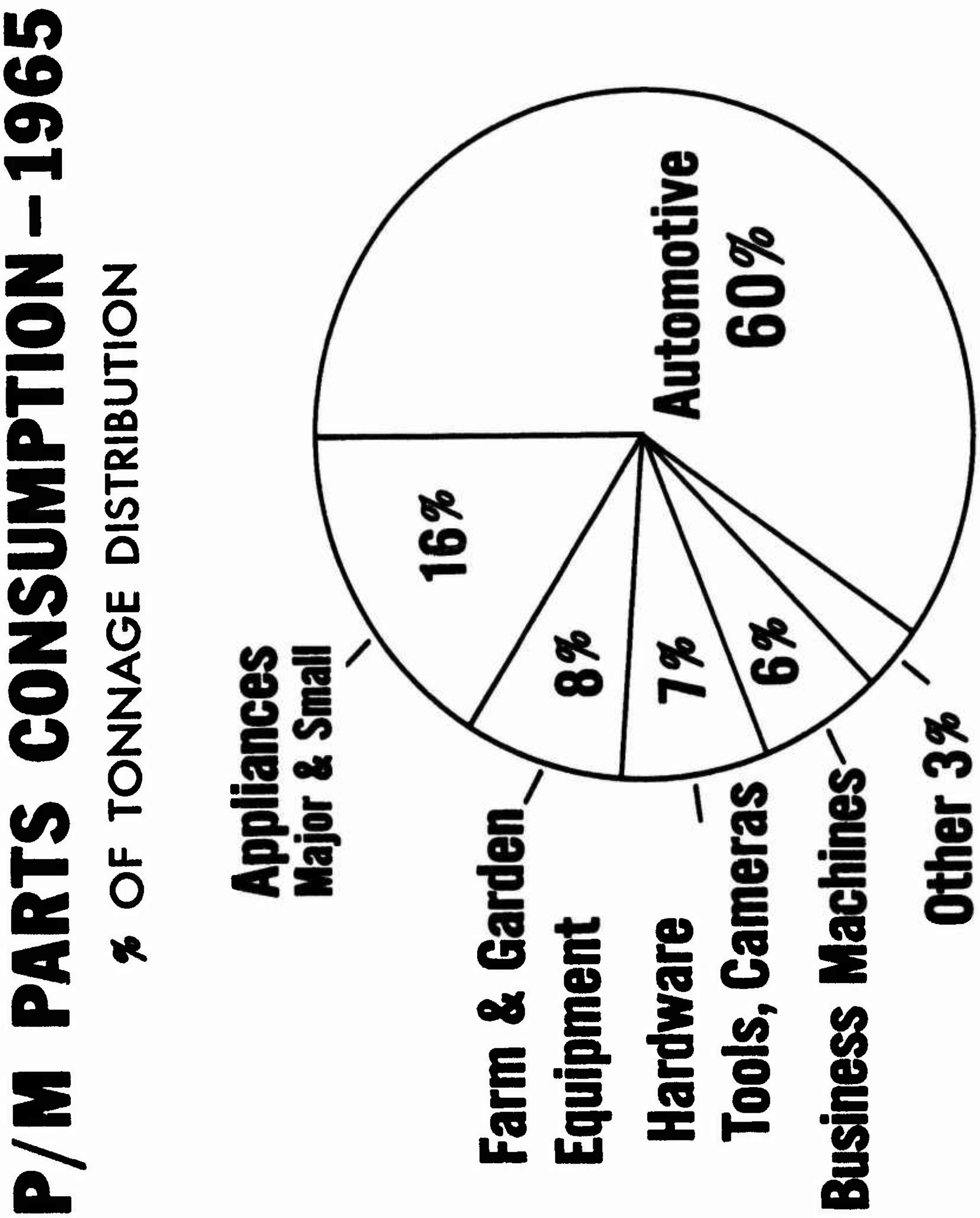
"The powder metallurgy process," states Parker White Metal, "permits the economical manufacture of brass and bronze parts, which when assembled to die castings, provides corrosion resistance without secondary finishing, and guarantees reproduceability of close tolerances."

Receiving Awards of Distinction for the successful design and production of these outstanding parts are Mr. W. Thomas Parker of Parker White Metal Co., and Mr. Olie Boughton of American Optical Co., Instrument Division.

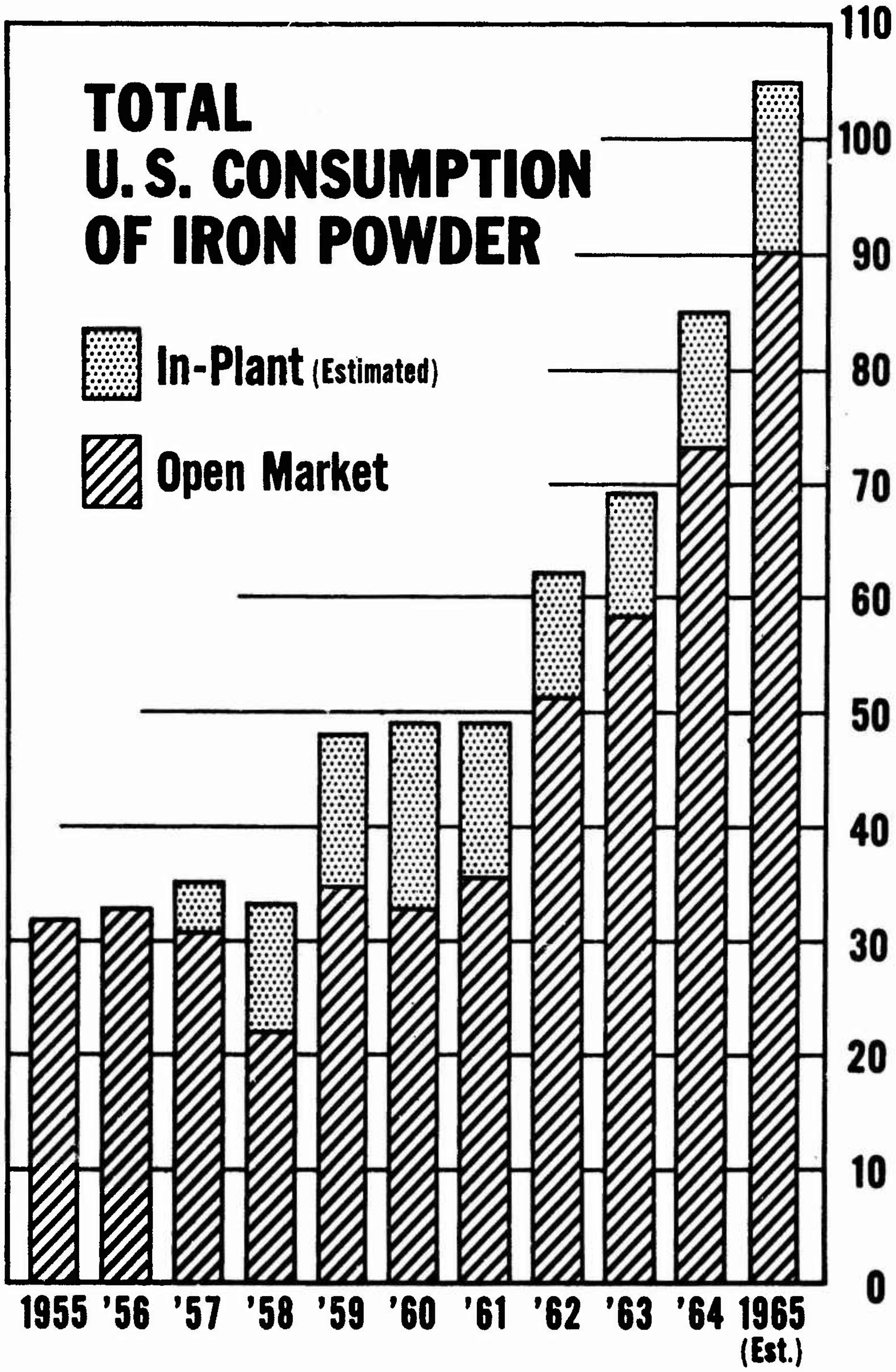


3

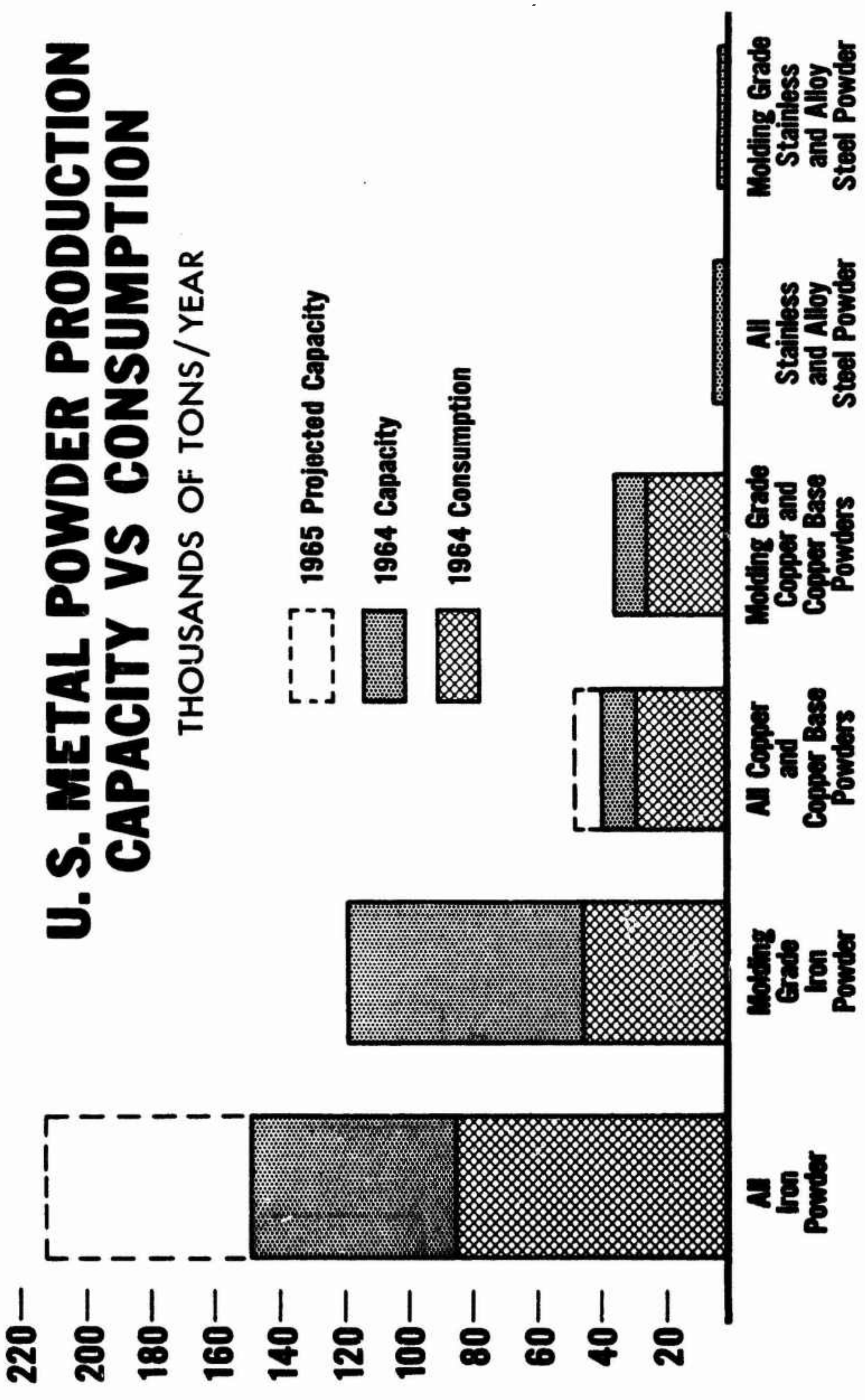
Courtesy of METAL POWDER PRESS



Courtesy of Metal Powder Industries Federation



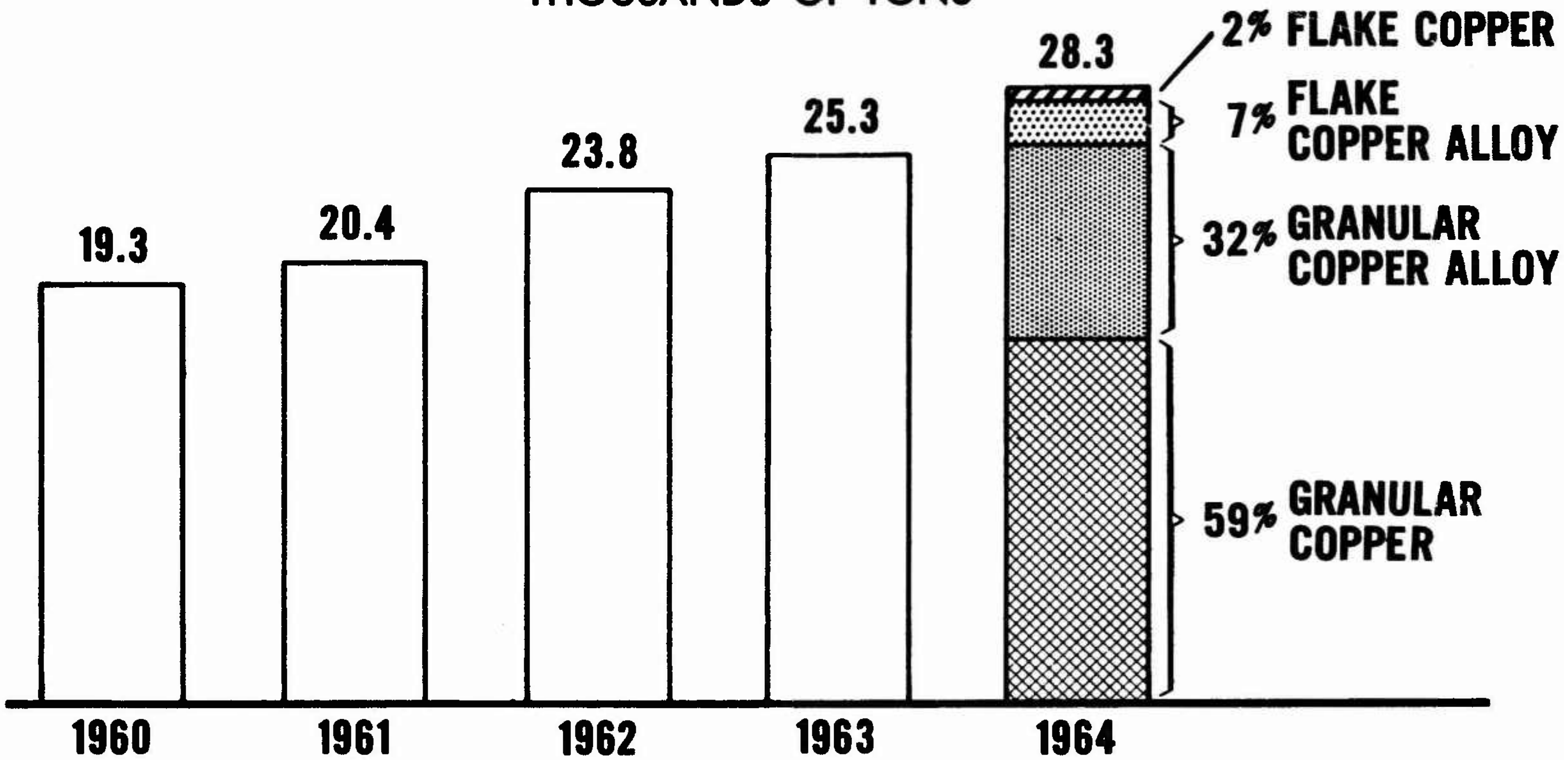
Courtesy of Metal Powder Industries Federation



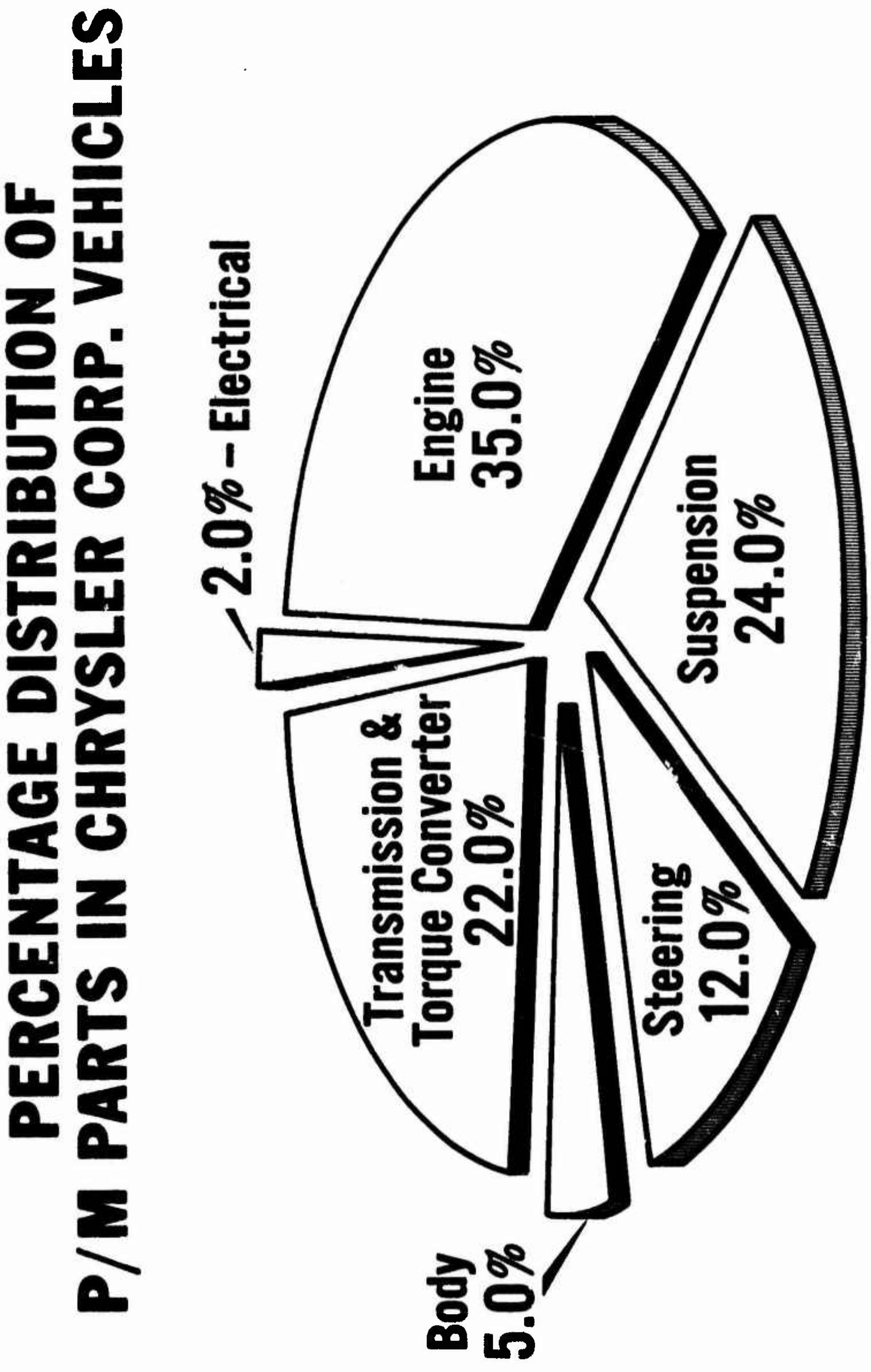
Courtesy of Metal Powder Industries Federation

SHIPMENTS OF
COPPER AND COPPER ALLOY POWDERS

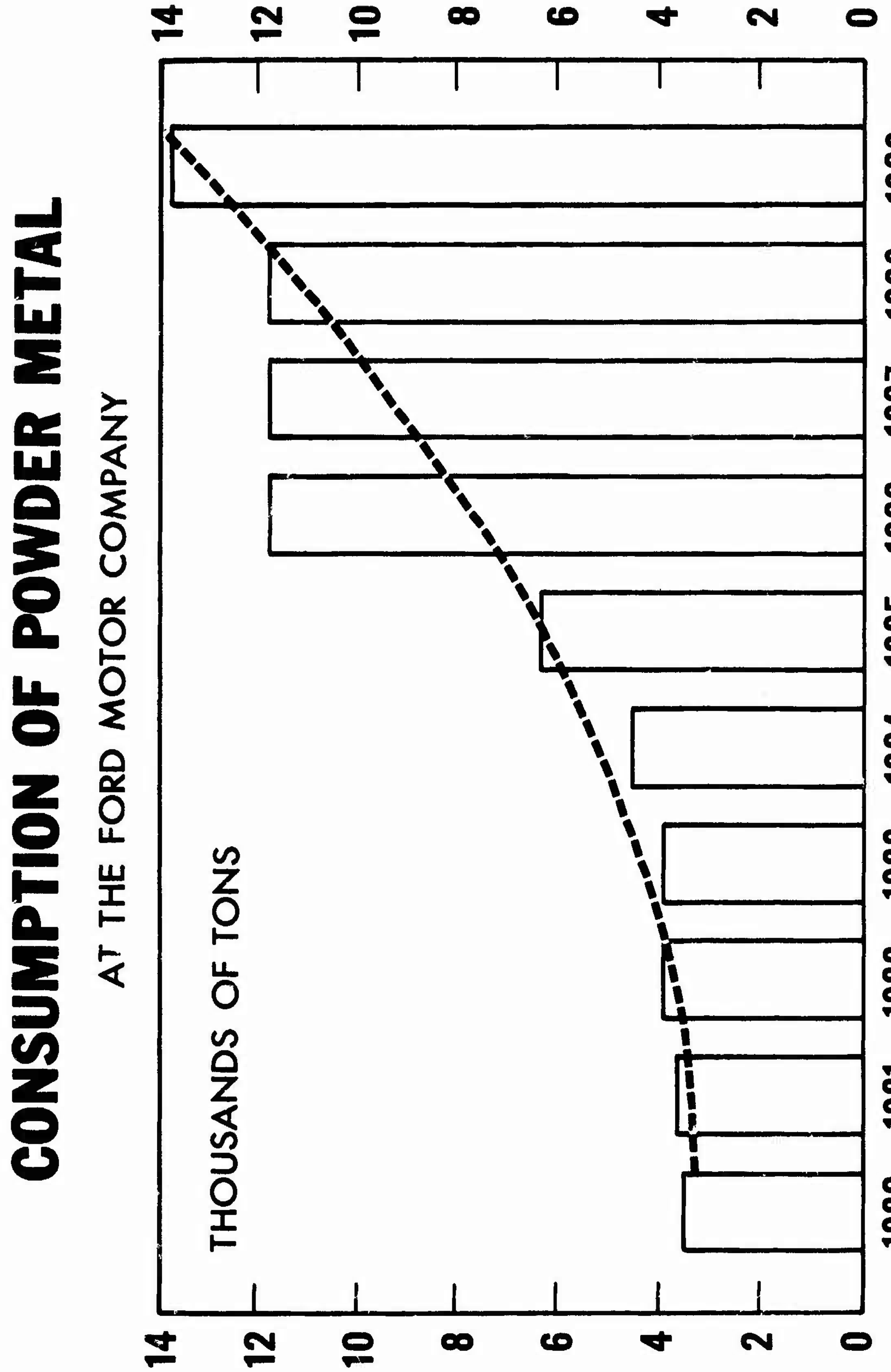
THOUSANDS OF TONS



Courtesy of Metal Powder Industries Federation



Courtesy of Metal Powder Industries Federation



Courtesy of Metal Powder Industries Federation

i. APPLICATIONS AND PICTORIAL ILLUSTRATIONS FROM THE POWDER METALLURGY PROCESS

Why You Should Consider Powder Metallurgy Parts For Your Products

Powder metallurgy is a mature technology backed by a vigorous, dynamic industry that has had a spectacular growth and promises an even greater potential. It is being increasingly used as a source for many different components in practically every industry. Among the many varied applications are those listed below. The various reasons for their use are detailed on the following pages.

CONSUMER PRODUCTS . . .

parts for alarm clocks, cameras, electric shavers, and household appliances.

AUTOMOTIVE . . .

bearings, gasoline filters, electrical contacts, gears, pump components, cams, levers, and washers.

RECREATIONAL PRODUCTS . . .

automatic pinsetter components, do-it-yourself hand and powered tool parts, piston rings, bearings, and structural parts for outboard motors and small gasoline engines.

BUSINESS MACHINES . . .

structural parts and bearings for typewriters, cash registers, adding machines, calculators, and computors.

ELECTRICAL AND ELECTRONIC . . .

components such as lamp filaments, storage batteries, magnets, magnetic cores, motor and generator brushes, slip rings, and electrical contacts for controls and switches.

AGRICULTURAL EQUIPMENT . . .

farm machinery structural components, bushings and bearings.

INDUSTRIAL APPLICATIONS . . .

machinery components, self-lubricating bearings, motor and pump parts, cutting tools, turbine blades, and welding electrodes.

MILITARY USES . . .

frangible bullets, rotating bands, armor-piercing projectiles, structural parts for ammunition, weapons, aircraft, and missiles.

ATOMIC ENERGY . . .

components such as fuel elements, moderators, and control rods.

Advantages of the Process

The powder metallurgy industry's methods of manufacture and its materials have built-in advantages not enjoyed by most other metalworking processes. Besides performance under uncommon operating conditions (no oil), proven reliability, tailor-made properties, high precision, dependable reproducibility, self-lubrication, as well as the unique property of alloying metals that cannot be combined in molten form—users are spared the investment of capital in machines. They need not carry inventories of special bars or strip. They do not face excessive lead times. They can turn to automation because of the assured accuracies of powder metallurgy parts and even with all these plus factors, powder metallurgy parts usually are more economical than others. It offers to the user a method of increasing the value of his end-product without adding to his costs and often at cost savings.

Reliability, reproducibility, quality and precision are bywords in modern powder metallurgy technology. Advances in tooling and design have produced precision in the ten-thousandths range and physicals impossible to achieve just a few years ago. Through such steps as infiltration, heat treatment, or impregnation with oil or even plastic—surface finish, strength, lubrication and corrosion resistance can readily be built into powder metallurgy components. Longer life, greater adaptability, better performance, all coupled with enhanced value are standard results today.

PRECISE CONTROL

of the materials and their properties is a most important advantage that is unique to the powder metallurgy process. Starting with high-purity powder particles, everything that happens in the creation of the finished product can be accurately controlled. This permits a wide variation in physical and mechanical properties while assuring performance characteristics of consistent uniformity. Impurities, internal stresses, gas pockets, and similar faults common to other processes, are eliminated.

VERSATILITY

is an important benefit. Practically any desired metal, alloy, or mixture of metals—including combinations not available in wrought forms—can be produced in this way. Copper, nickel, brass, bronze, iron, low and medium carbon steels, alloy steels, and stainless steels as well as the precious metals, the refractory metals and the aerospace metals are among the materials available through powder metallurgy.

When desired a single part can be made hard and dense in one area, and soft and porous in another. Also, powder metallurgy parts can be produced in a wide range of shapes with irregularly shaped holes, eccentrics, flats, splines, counterbores, and involute gears. Two or more parts can be combined into a single unit, thus eliminating assembly costs and simplifying the product design. Also, keys, keyways, and other fastening devices can be made integral with the part, or components can be fabricated in sections and joined by press-fitting or brazing.

PROPERTIES

can be varied over a wide range and "tailor-made" to suit a specific application. Physical properties can range all the way from low density, highly-porous parts having a tensile strength as low as 10,000 psi, to high density, minimal porosity pieces having a tensile strength of 180,000 psi or more. Standard alloys which offer a wide range of mechanical properties are listed in the chart on page 23.

SELF-LUBRICATION

is a feature unique to powder metallurgy materials. The controlled network of small pores in the parts can be filled with oil or other desirable lubricants selected for contact with any variety of wearing surfaces. This feature can result in substantial savings by eliminating the need for a costly lubrication system which generally does not perform the function as satisfactorily.

ECONOMY

is an important consideration in the selection of parts made by any process. Powder metallurgy is an economical process because of the rapid, mass-production techniques employed, the reduction or complete elimination of subsequent machining or finishing, and the reduction or elimination of material and scrap losses.

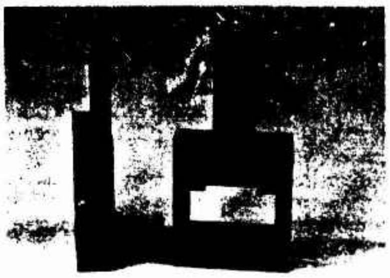
1-SUBSTANTIAL COST REDUCTIONS

HIGH SPEED MASS PRODUCTION TECHNIQUE WITH MINIMUM TOOL COST

Because most powder metallurgy parts can be formed in a single pressing operation from mixes of prepared metal powders, continuous high speed production can be practically combined witb long tool life and low frequency of tool replacement.

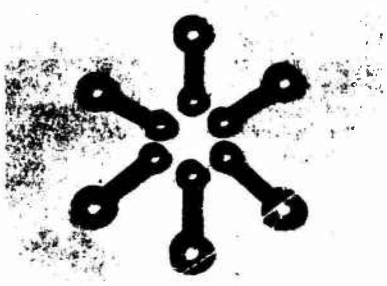
ELIMINATION OF SLOW, COSTLY INDIVIDUAL MACHINING AND MULTI-STEP PRODUCTION METHODS

Hardness and strength are imparted to powder metal parts *after* shaping making it possible to form complex shapes which normally would require a combination of casting or stamping with one or more individual machining operations.



ELIMINATION OF ADDED SECONDARY FINISHING OPERATIONS

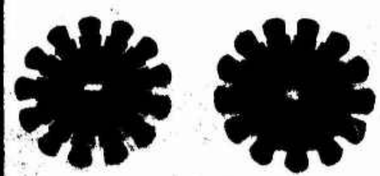
Parts made by powder metallurgy show no tool marks and present an excellent surface ready for immediate assembly. Finish on top and bottom surfaces, as sintered, are 30-50 microinches; in holes and on sides, 20-30. Coining can easily provide an even finer finish if required.



ELIMINATION OF COSTLY SCRAP

Because powder metallurgy parts are formed to their desired shape from a mixture of metal powders rather than machined or stamped from oversized blanks of solid metal, there is no "hard" metal trim or scrap.

2-INCREASED DESIGN and



Courtesy of Dixon Sintaloy Inc.

RODUCTION EFFICIENCY

COMBINING PARTS FOR SINGLE-PART PRODUCTION

Many parts normally requiring several separate pieces when produced by other methods can be formed as a single part by powder metallurgy. Aside from cost, added advantages include greater strength, quieter operation and less wear in use with resultant longer parts-life.

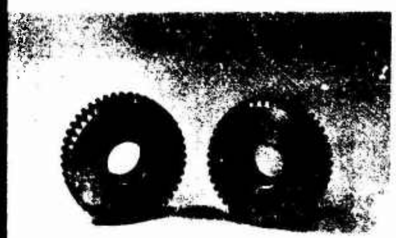
ECONOMICAL USE OF INTRICATE SHAPED THEORETICALLY IDEAL PARTS

Often, cost considerations make certain "ideal" parts impractical for mass production use due to the amount of individual machining necessary to form such a part by conventional methods. Powder metallurgy has often proved to be the means by which such theoretically perfect parts could be produced economically enough to be used in a competitively priced product.

FEWER SUBASSEMBLIES TO FINISHED PRODUCT

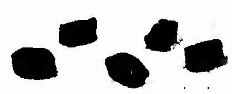
Many subassemblies of separate parts are dictated not by function but because the various shapes and surfaces required cannot be practically imparted to a single part by conventional methods. Powder metallurgy can often provide the means of forming a single metal part into the required complex, thus eliminating both the production steps required to form separate parts and the subassembly operation, itself.

3-IMPROVED PARTS and PRODUCTS CHARACTERISTICS



PRECISION QUALITY CONTROL

Dixon powder metal parts are precision parts with normal tolerances on small parts up to 2" of ±.001"/inch radial and ±.005" on axial dimensions. Strict quality control is in effect throughout production, and dies as well as metal characteristics are periodically checked during each production run to insure accurate, uniform parts with identical properties.

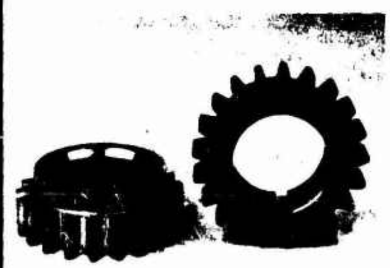


CONTROLLED OR "TAILOR-MADE" METALS CHARACTERISTICS

Because the various metals used in this process are initially in powdered form, they can be combined with each other in innumerable variations or with other non-metallic materials to achieve special desired parts characteristics. Physical properties such as density and porosity can be widely manipulated and consistently maintained throughout a given production run.

BUILT-IN SELF-LUBRICATION

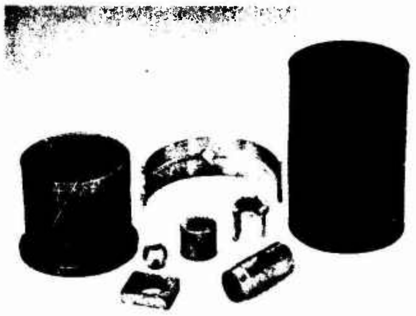
This metal-parts characteristic, only available through powder metallurgy, is extremely veluable in friction applications. Controlled porosity allows a network of small pores to be filled with one of several heavy-duty lubricants suitable for a variety of wearing surfaces. In use, heat expands the lubricant to the surface of the part; when the part cools, it is reabsorbed for future use.



HARDER METALS FOR LONGER LIFE

Costs for producing metal parts by conventional methods are often drastically increased when high strength or extreme hardness are required characteristics. These same characteristics are readily obtainable in powder metal parts by proper selection of alloys, but do not as directly affect the cost of production because they are impartad to the part *after* it has been shaped.

Courtesy of Dixon Sintaloy Inc.



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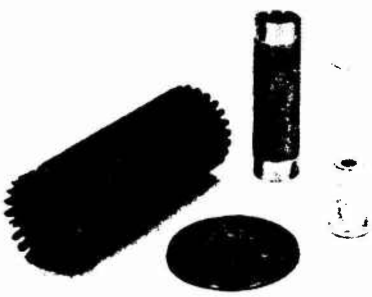

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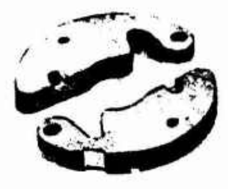


4

CONTROLLED POROSITY FOR LUBRICATION

Based on the self-lubrication feature described above or elsewhere in this Guidebook, conventional powder metallurgy bearings hold from 10 to 40 per cent of oil by volume, and supply additional lubricant to the bearing surface as heat expands the oil. The oil is reabsorbed on cooling, ready again for use when needed. Typical self-lubricating applications are shown in Fig. 2.

CONTROLLED POROSITY FOR FILTRATION

Controllable porosity in powder metallurgy parts is also important in the creation and application of filters. Such filters can separate or pass materials selectively, diffuse the flow of gases or liquids, regulate the flow or pressure drop in supply lines, or act as flame arrestors by cooling gases below combustion temperatures. Filters can be produced with almost any configuration, Fig. 3, including sheets, tubes and a variety of shapes.

CONTROLLED MASS-WEIGHT-DENSITY

The feature of accurately controllable mass-weight-density ratio in powder metallurgy parts is important for many applications. Typical examples are the counterbalances shown in Fig. 4, governor weights for movie camera shutter assemblies.

HIGH DENSITY — LOW POROSITY

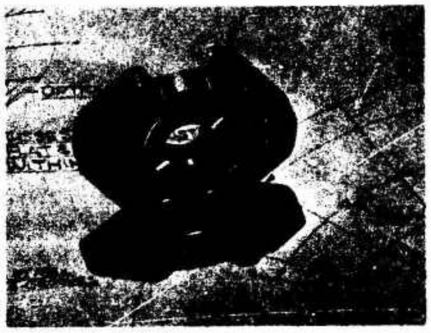
High density—low porosity parts can be fabricated to a 95% minimum solid by pressing, sintering, repressing, and usually resintering. These parts have higher physical and mechanical properties because impact strength, tensile strength, yield strength, and elongation increase with decreasing porosity. By heat treating, tensile strengths of 180,000 psi or more can be obtained. Carburized and hardened high density iron parts exhibit a sharply defined case.

The 5% maximum porosity allows these parts to be treated as conventional wrought materials. Since there is no interconnecting porosity—subsequent operations such as heat treating and plating can be performed as usual. High density materials are usually specified for structural parts requiring high strengths, close tolerances, or low porosity.

PRECISE TOLERANCES AND SMOOTH FINISHES

Thrust plates, such as the one seen in Fig. 5, which form the housing for the pump rotor on an automotive power-steering system, must withstand pressures up to 1250 psi after steam treatment. With powder metallurgy, close tolerances and smooth finishes are consistently maintained, thus eliminating a considerable amount of the machining previously required. For example, the bore is molded to a diameter between 0.5870 and 0.5875, and no machining of this surface is necessary. Also, other dimensions, the dowel-pin holes, and the clean, sharp ports are held to relatively close tolerances.

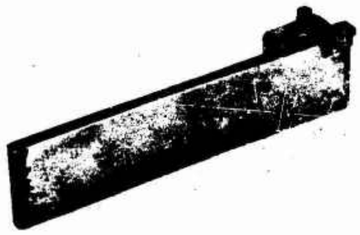
In changing the thrust plates from machined cast iron to powder metallurgy, the quality and performance of the parts were improved, their size reduced, and their cost lowered. Also, their hardness, compressive strength, and resistance to wear were increased by steam treating. The inherent self-lubricating properties of the burnished bore make it an ideal bearing surface, and eliminated the need for a costly bronze bushing and special lubrication system.



5

DAMPING OF VIBRATION AND NOISE

The self-damping nature of powder metallurgy parts permits quieter operation and smoother action. Ringing, common with wrought steel gears and other parts, is eliminated. This is an important benefit in dictating machines, business machines, air conditioning blowers and similar products. The excellent damping characteristics are also an advantage in copper-infiltrated toolholders, Fig. 6, as they minimize vibration, reduce tool wear, and help to maintain closer tolerances.



6

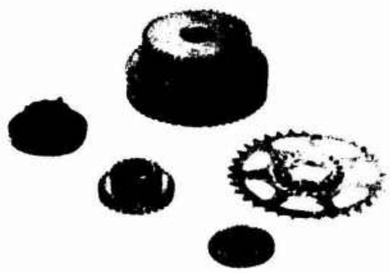
LESS WEAR . . . LONGER LIFE

Powder metallurgy is used to produce three vital parts in a record-playing mechanism for juke boxes because of the unprecedented wear resistance and long life obtained, as well as the impressive production savings realized. The three parts, Fig. 7, are a sprocket pinion, clutch member, and worm gear hobbed from a powder metallurgy blank. Compacted from 20 per cent copper-iron powder, the parts have replaced screw machine products which cost five times as much. Life of the mechanism is estimated at 10 years or 2 million record change cycles. Maintenance costs have been reduced because of the self-lubricating material, and a quieter assembly has resulted.

7

SAVING SPACE BY COMBINING PARTS

Space savings, higher strength, quieter operation, improved accuracy, lower cost, and other design advantages result from one-piece powder metallurgy parts that require two or more separate pieces when made by other methods. Typical one-piece powder metallurgy parts that combine gears, pinions, ratchets, and sprockets, are shown in Fig. 8.



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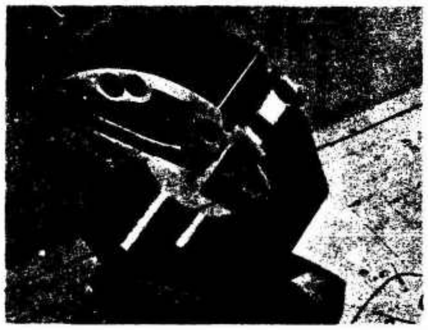

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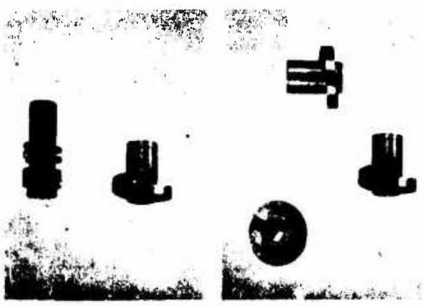

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12

13

SPECIAL ALLOYS OBTAINABLE ONLY BY POWDER METALLURGY

Powder metallurgy permits combining materials which cannot be produced in any other way. For example, carbides and other materials too hard or too brittle to be shaped in any other way are produced by this method. The unique material combinations illustrated in Fig. 9 are a heavy-duty, metallic friction material made from copper, tin, iron, lead, graphite, and silica; a graphite-bronze slip ring segment, and a copper-carbon brush.

INTRICATE SHAPED PARTS

Powder metallurgy is ideal for the production of unusual or complex shaped parts that are almost impossible or impractical to obtain by other methods. For example, while the compressor housing shown in Fig. 10 can be machined from a casting, the cost would be substantially more than when made by powder metallurgy. In fact, the savings in scrap over cast iron, resulting from the elimination of rough machining operations, paid for the powder metallurgy tooling. Also, the housing could be made smaller and the sections thinner, thus reducing the size and weight of the final assembly.

Cams, which are difficult and expensive to machine, are another good application for powder metallurgy. For example, the distributor cams seen in Fig. 11, which are part of the complex mechanism in automatic pinspotters found in the nation's bowling alleys, are produced in this way. While these cams could be machined from steel, as was the original part shown at the far left, the oil-impregnated, pre-alloyed bronze powder parts are produced at a substantial cost saving. Also, the improved sliding characteristics are essential to prevent galling and binding.

The gear and cam assembly for a fire-alarm pull-box, seen in Fig. 12, is made by powder metallurgy. These parts would be almost impossible to produce by conventional methods of gear cutting.

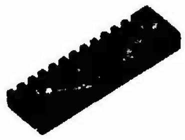
IMPROVED PRODUCT AT LOWER COST

Improved polarizers (armatures) for direct-current motors are produced by powder metallurgy at substantial cost saving over the original parts. Previously, the parts were machined as blanks, slots were milled in their peripheries, and small pieces of magnetic iron were staked in the slots. In addition to the higher cost of this method, the staked parts tended to loosen. With powder metallurgy, "green" or unsintered inner compacts of pre-alloyed bronze are inter-nested with sintered outer compacts of steel powder. When the assemblies are sintered, the inner compacts expand and are physically bonded to the outer members. The outer members are then machined to expose the inner cores, thus forming alternating magnetic and non-magnetic sections. Fig. 13.

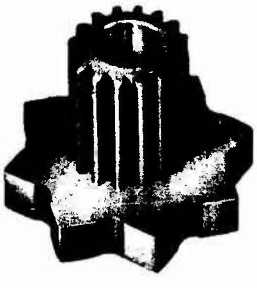
GRAMIX gears

FIVE CENT PIECE FOR COMPARING
GRAMIX PARTS WHICH ARE ACTUAL SIZE

Iron Oil Pump Gear



Bronze Gear Rack



Iron Drive Gear

Nickel Silver Liquid Pump Gear

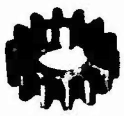
Iron Sprocket Gear

Nickel Silver Insert

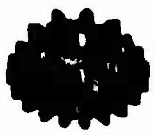
Bronze Drive Gear

Iron Oil Pump Gear

Iron Magneto Gear



Iron Magneto Gear



Bronze Production Counter Gear

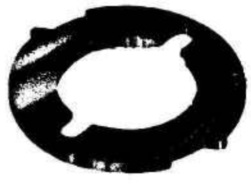
GRAMIX cams, ratchets and pawls

FIVE CENT PIECE FOR COMPARING
GRAMIX PARTS W[illegible] ARE ACTUAL SIZE

Iron Cam

Iron Cam Follower

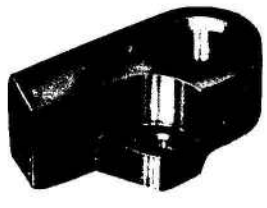
Bronze Counter Trigger



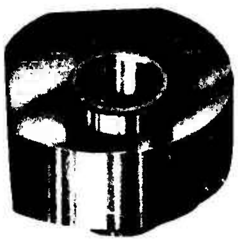
Iron Actuating Cam

Iron Die Block

Iron Timing Cam

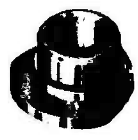


Iron Ratchet



Iron Actuating Cam

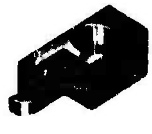
Iron Lock Ratchet



Iron Eccentric

Iron Switching Cam

Bronze Instrument Cam

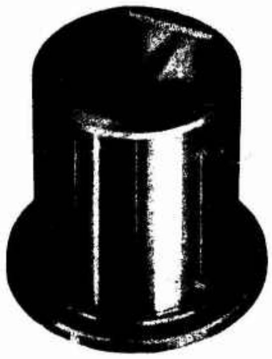


Iron Ratchet

GRAMIX parts for special motions and assemblies

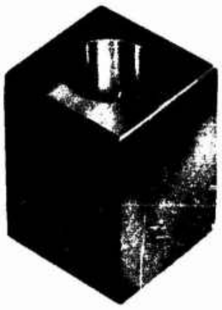
Bronze Reciprocating Bearing

Bronze Gear Hub

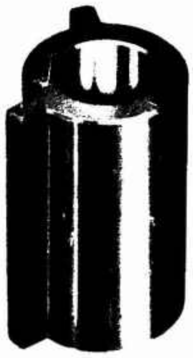


Bronze Guide Bearing

Iron Feed Roll

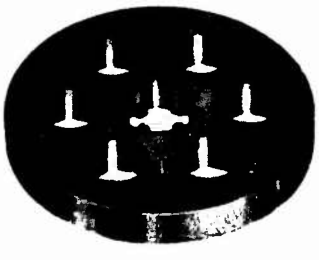


Iron Slider

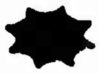


Iron Agitator Roll

Bronze Eccentric Bearing

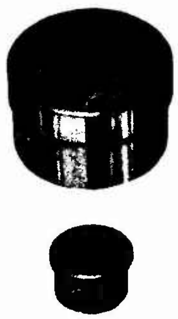


Bronze Splined Gear Blank



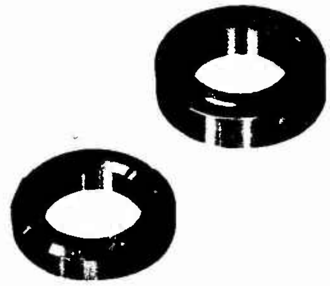
Bronze Adjusting Nut

other unusual GRAMIX parts

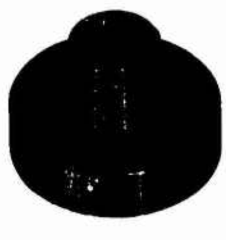


Nickel Silver Valve Seats

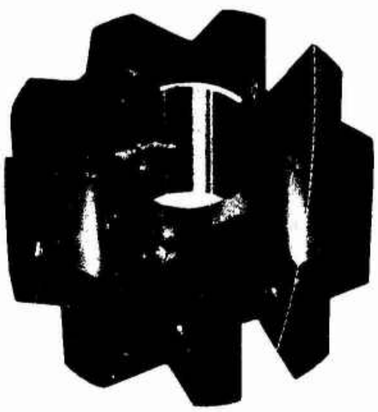
Iron Record Guide



Iron Packing Gland Retainer Rings



Bronze Gear Hub



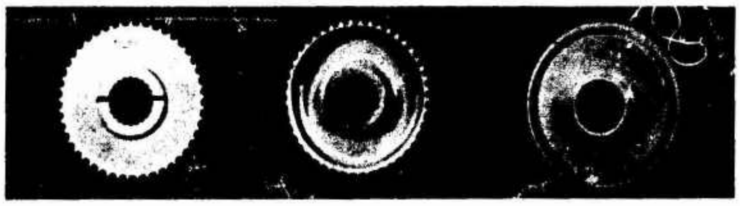
Iron Governor Hub

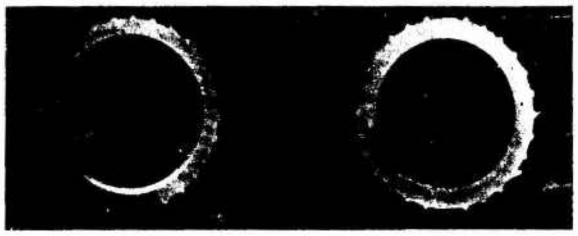
Bronze Token

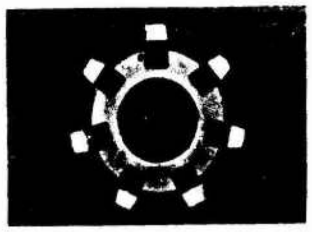
Iron Hinge

Nickel Silver Shower Head

Iron Hinge Bracket





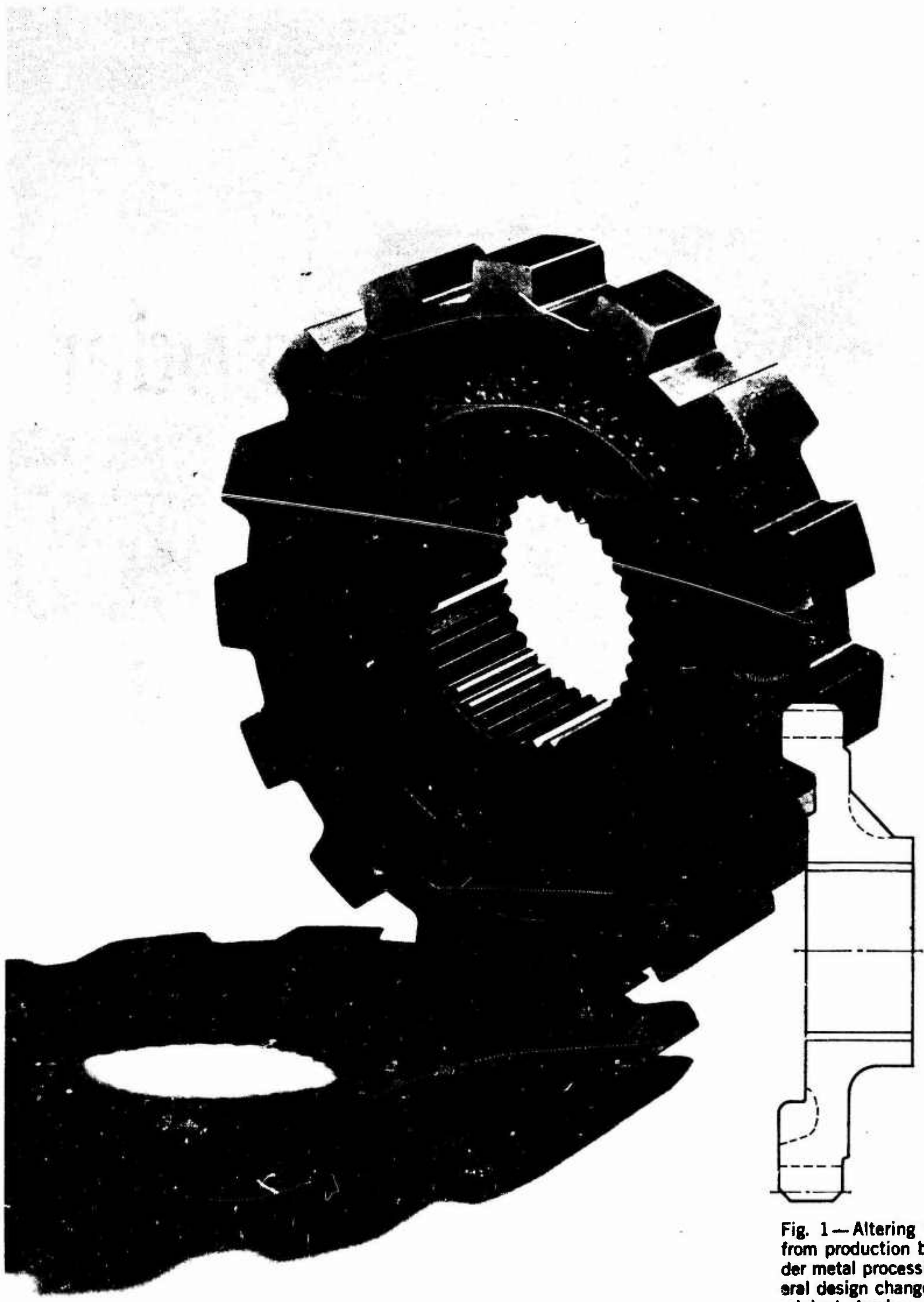


Powder Metal Usage at Ford

By *JOHN CENKO**

Engineers of Ford Motor Co. expect to increase annual powder metal usage from the present 6,200 tons to 14,000 tons by 1969. With the development of better powders and processing methods, more stress-bearing applications should appear in such critical assemblies as automatic transmissions and motors.

Powder metallurgy has advanced greatly in the last decade. Exemplifying this advance are the powder metal parts (for Ford automatic transmissions) shown above. Ten years ago, none of them existed in powder form. More recent additions to this collection of parts, together with others currently in development, promise a substantial increase in usage of powdered iron. In fact, consumption of powder at Ford has been assuming a hyperbolic trend. From 1960 to 1965, powder tonnage rose from 3300 to 6200 tons, and an abrupt increase (to around 12,000 tons) is projected for 1966.



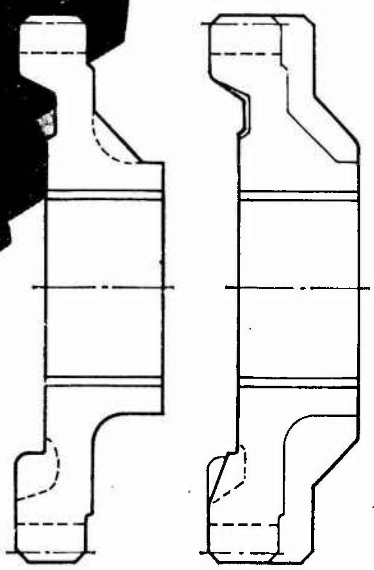
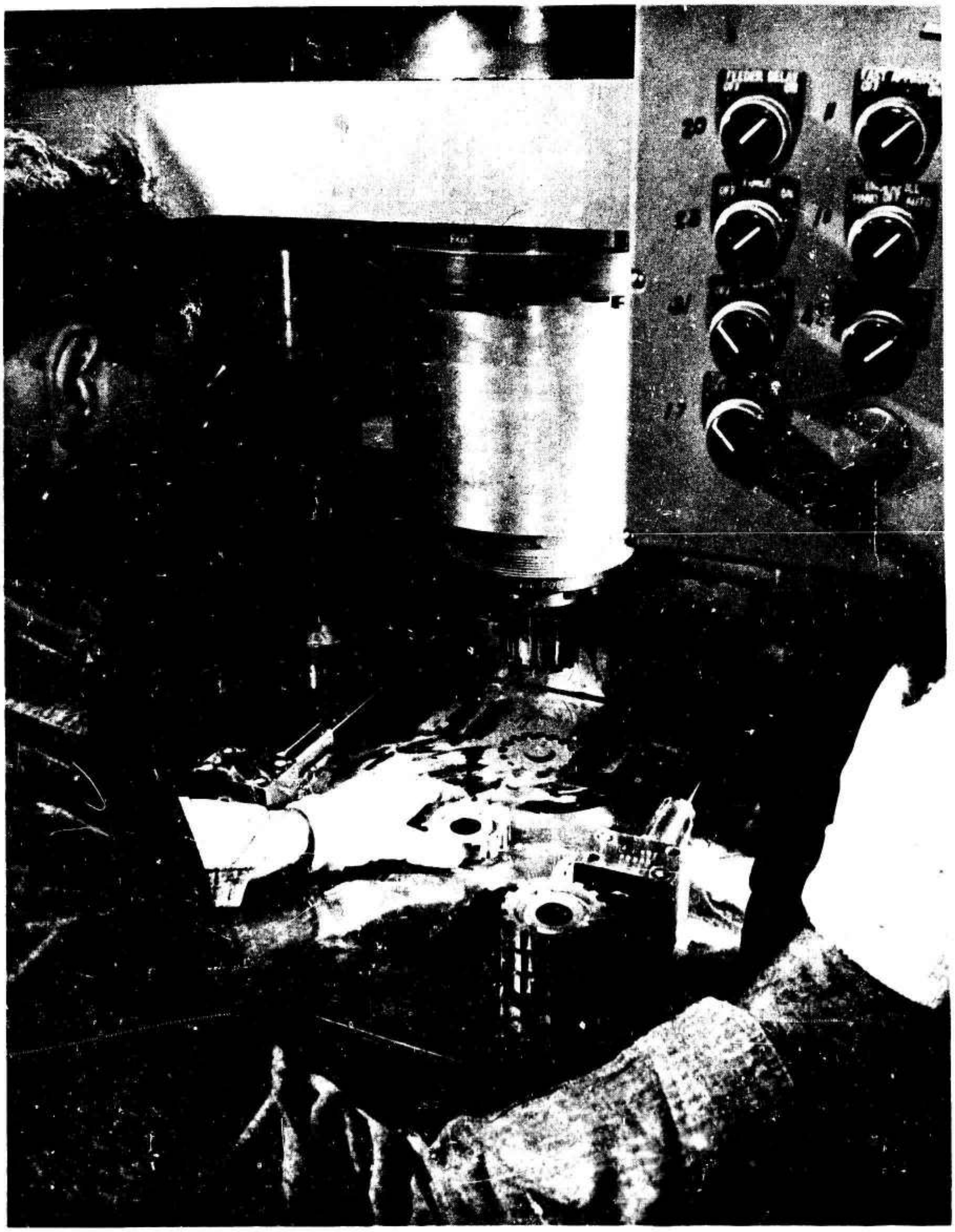


Fig. 1—Altering the parking gear from production by forging to powder metal processing called for several design changes. Design of the original forging is at left; final powder metal design is at right.

Sintered steel parking gear used in Ford transmissions and supplied by Keystone Carbon Company, St. Marys, Pennsylvania.

Courtesy of Keystone Carbon Company

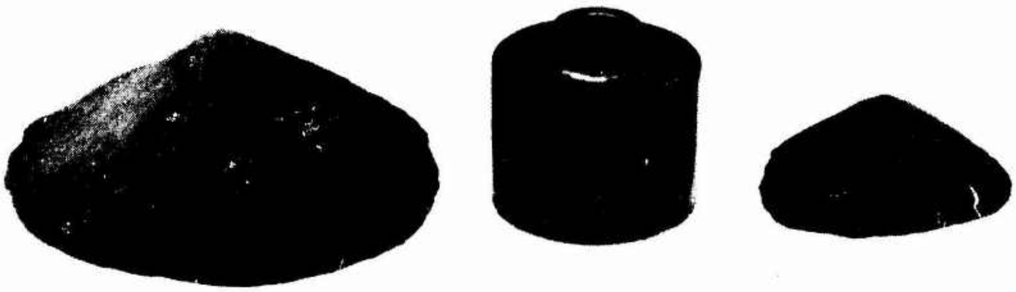


Close-up view of molding operation on sintered iron parking gear.

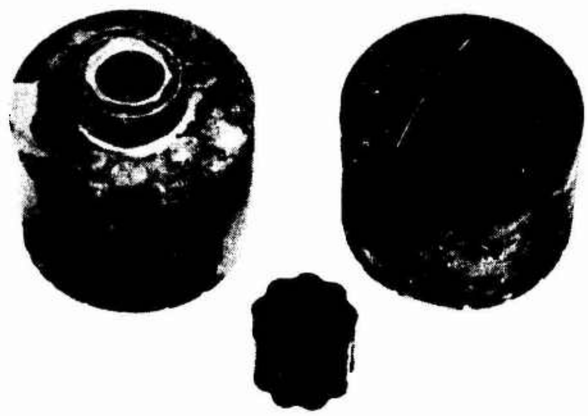
Courtesy of Keystone Carbon Company

Coining or sizing operation as performed on sintered iron gear.

Courtesy of Keystone Carbon Company



The pile of iron powder (left) and the infiltrant powder (right) are needed for each large (4-1/2" dia.) pump block.

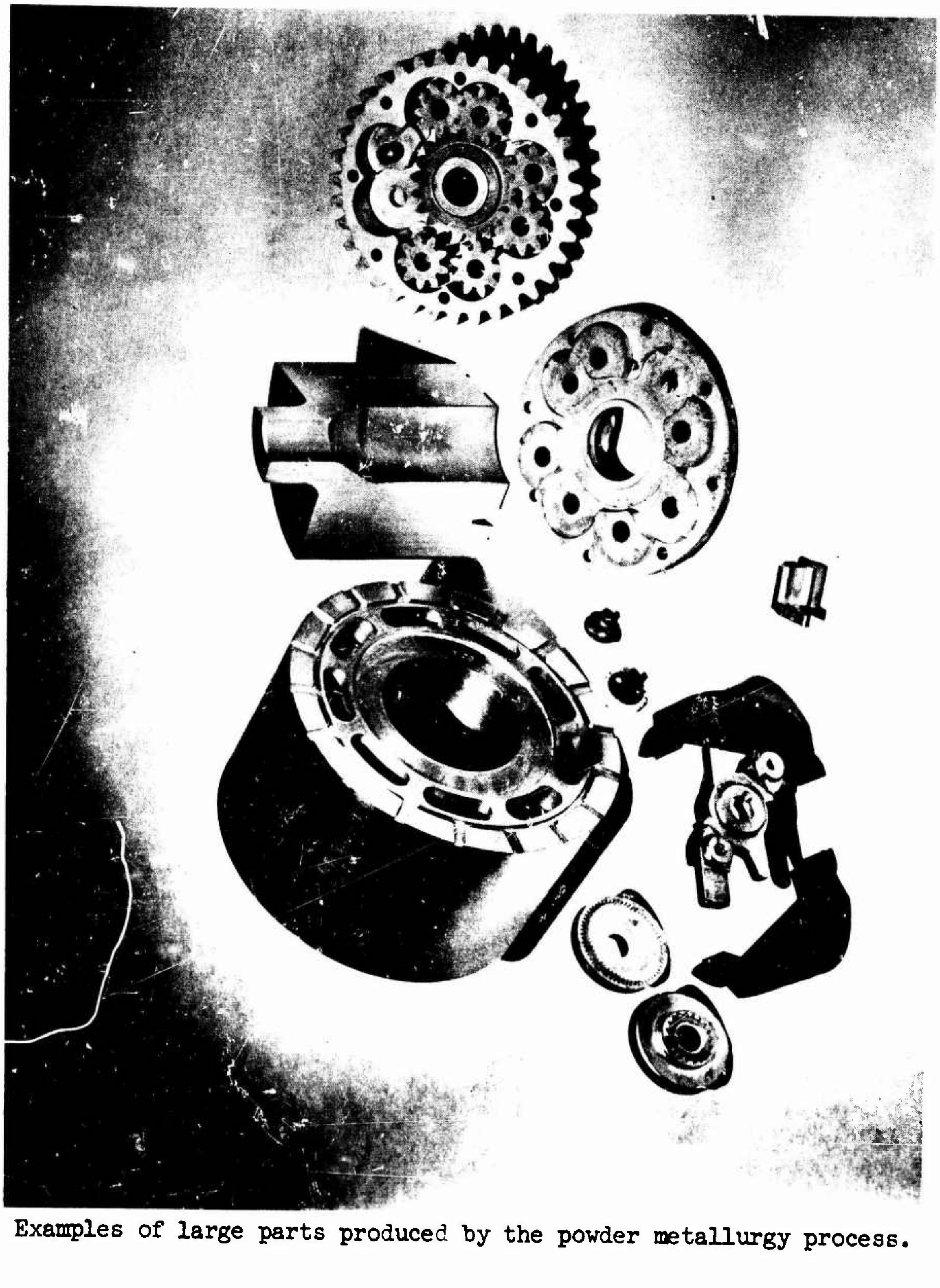


Block for a 45 gpm pump is shown (left) as delivered by the powder metal fabricator; and (right) fully machined and weighing 20 pounds. The smaller block is for a 5 gpm pump and weighs ½ pound, machined.

How the parts are made. The large blocks require about 22 pounds of iron powder to make the preform or skeleton and about 5 pounds of copper base infiltrant powder (Ferraloy uses a special infiltrant powder) The iron skeleton is pressed on a 1500 ton molding press and presintered for 4-1/2 hours (this is the complete furnace cycle). After presintering the preformed infiltrant is placed on the iron skeleton and the assembly resintered. The second furnacing is again 4-1/2 hours for the complete cycle.

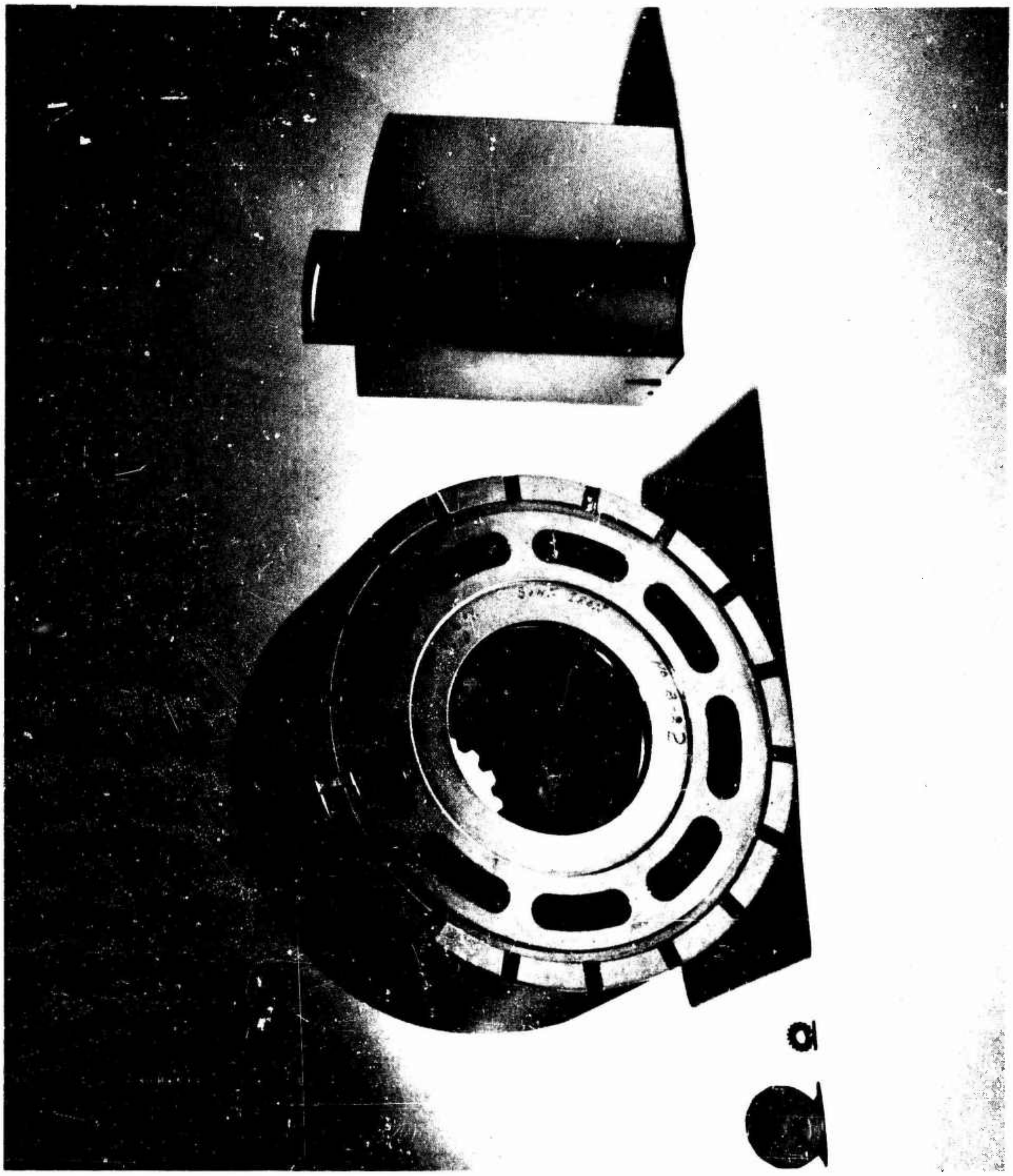
No machining is done by the fabricator and Vickers has only simple machining to do; face, gun ream the 9 piston bores, and broach the splined center hole.

With the basic powder metallurgy technique for forming the pump blocks, and the greatly reduced machining now required, Vickers has been able to show a saving of over 25% in the manufacturing cost of this style pump block, over that of a previous design which utilizes wrought bronze.



Examples of large parts produced by the powder metallurgy process.

Courtesy of Metal Powder Industries Federation



P/M iron pump housing infiltrated with copper weighs 15 pounds. Canadian nickel made from nickel powder and small precision high-strength steel gear made from iron powder.

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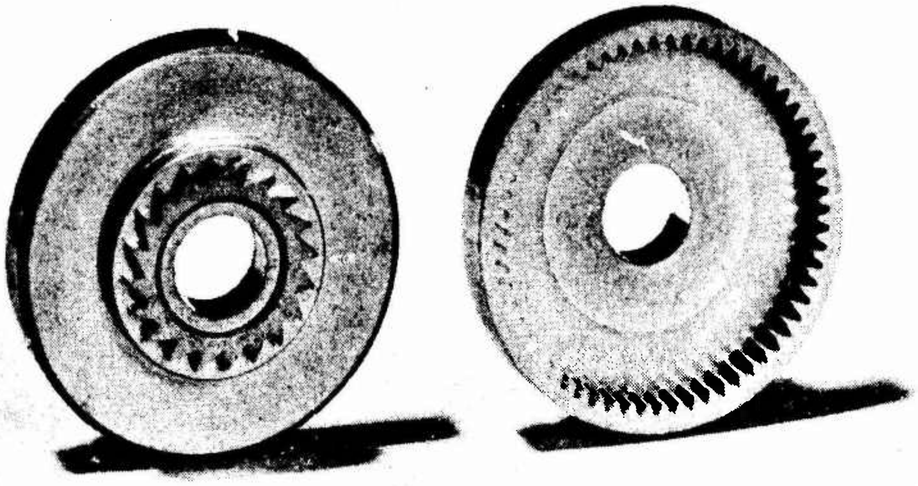
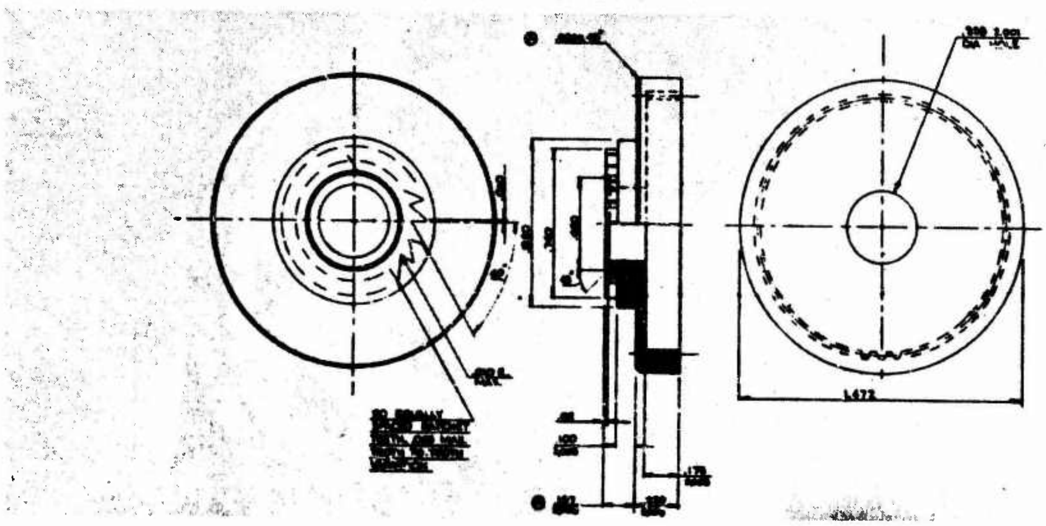




Tolerances

Concentricity, internal bore – total composite error .004 maximum.

Tooth to tooth composite error – .0015.

Thickness – ±.003

Gear Design Characteristics

Diametral Pitch – 48

No. of teeth internal gear – 62

Pressure Angle – 20°

Pitch Diameter – 1.2916

Class of gear – commercial 2 class B

Backlash in gear – .002 min. to .004 maximum.

Ratchet – 20 equally spaced teeth, .005 maximum tooth to tooth variation.

Material Specifications

Straight iron-carbon (ASTM-B 310-56T, class B type II)

Density range – 6.1 to 6.5 g/cc

Combined carbon – 0.25–0.60

From P/M Parts Engineering, Vol. 1, No. 1, 25M-KP-5/66, Courtesy of Metal Powder Industries Federation

How To Get Closer-Than-Commercial Tolerances

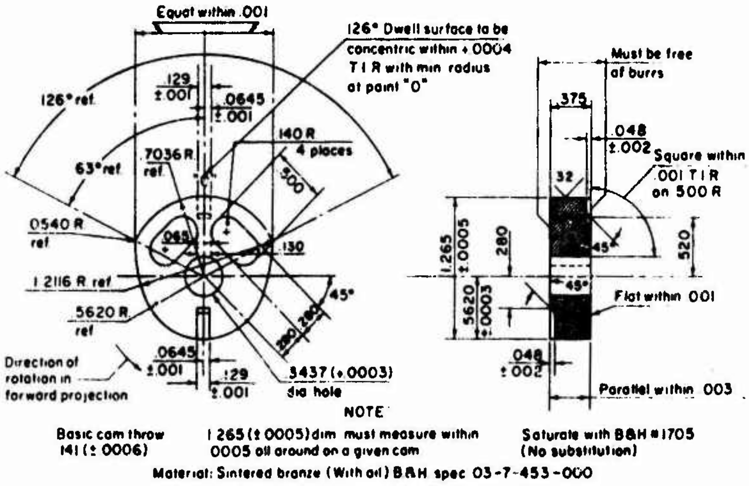
Tolerances don't always mean holding closely to dimensions. Tolerances can mean what variations in physical and mechanical properties your design will tolerate.

Tolerances can refer to corrosion resistance, surface finish, wear resistance, impact resistance, and many other physical and mechanical properties. In the powder metallurgy parts and the investment casting discussed in these first two articles close tolerances mean all these things as well as dimensional accuracy.

But to get these close tolerance parts, the designer must remember that:

1. *You will pay more per part than if commercial tolerances were specified.*
2. *It will take longer to get into production than if commercial tolerances were specified.*
3. *You will have to work closely with your vendor and be prepared to compromise wherever possible.*
4. *You may have to discard preconceived ideas about materials.*
5. *You must expect tooling costs to be much higher.*
6. *You must expect higher than normal inspection costs.*

If you are willing to accept these hard-to-live-with facts you can probably get the part you want, that will function properly, that will give you good service life, and that will, in the end, be less costly than machining from wrought stock or machining a rough casting.



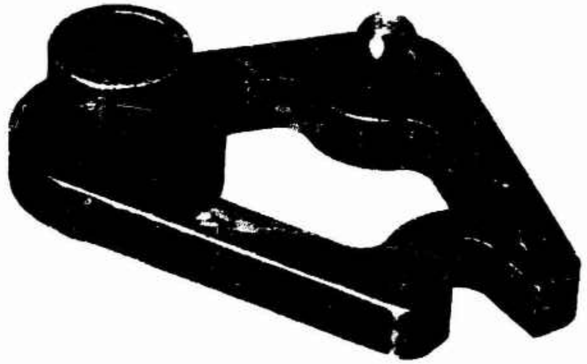
1. PULL-DOWN CAM advances film in movie projector.

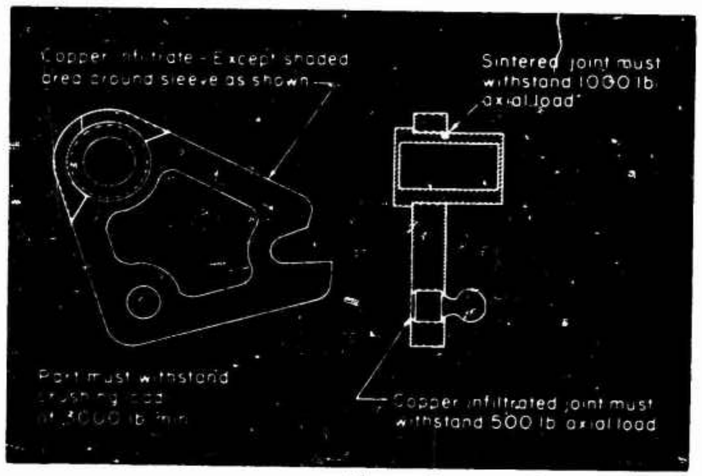
2. DRAWING shows tolerances required for cams.

Reprinted by special permission from The Industrial Publishing Company from the article "Powder Metallurgy Can Hold Tight Tolerances" as published in the March 1963 issue of PRECISION METAL MOLDING, (C) 1963.

AUTOMATIC TRANSMISSION PART

For the best performance, this part required three different materials. One of the parts, the pin, had to be made of SAE 1112 steel, probably a screw machine part. But the body and the bushing were metal powders.





Photos Courtesy Eaton Mfg. Co.

Both the bushing and the pin are bonded to the body during sintering and, to make the problem even harder, the body had to be infiltrated with copper, but only over a portion. The shaded area in the sketch was left uninfiltrated. The specifications and the drawing tell the requirements.

Application	Automatic Transmission
Service	Medium shock, medium torque load-heavy wear, high strength required.
Mechanical properties	Body 120,000 psi tensile, 0.5% elongation. Bushing 60,000 psi tensile, 0.5% elongation
Hardness	File hard all over
Heat treatment	Carbonitride and harden

POLE PIECES MADE FROM IRON POWDER

For such applications as windshield wipers, power steering, power brakes, heater motors, and others used by the automotive industry, the torque requirements dictate the motor design. On these fractional horsepower motors, the size of the pole pieces is one of the controlling factors. These pole pieces can be made from iron powders instead of wrought stock and show a decided manufacturing economy.

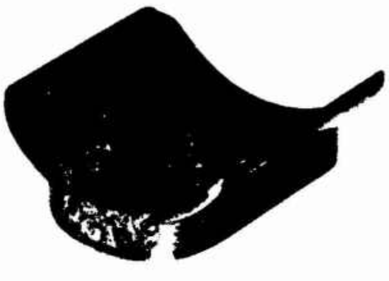


Photo Courtesy Eaton Mfg. Co.

ments for the piece are 19,000 psi tensile strength, 0.5% elongation, and 45 to 60 Rockwell F hardness.

The part is barrel finished to remove any burrs and to produce an overall smooth surface. There are no secondary machining operations.

HYDRAULIC BRAKE ANCHOR BLOCK

"Can you match the mechanical properties of steel?" This is one question most frequently asked of the powder metallurgist. Unfortunately, the answer has been "No" most of the time. Now, however, many fabricators are able to match, and even surpass, the mechanical properties of plain carbon steel.

An example of a part made from this alloy powder is shown. The requirements of the part are:

Material	Low-carbon, alloy steel
Requirements	High strength—medium shock—heavy wear.
Mechanical properties	Tensile strength 87,000 psi. Elongation in 2" 0.5%
Hardness	30 to 35 Rockwell C
Heat Treatment	Harden-oil quench, 350°F draw
Secondary operations	None
Surface finish	None

With material of this capability now available and with the skill of the vendor companies also available, there is little doubt that many of the parts now being made from wrought stock could be changed to powder metallurgy parts at a marked saving in cost.

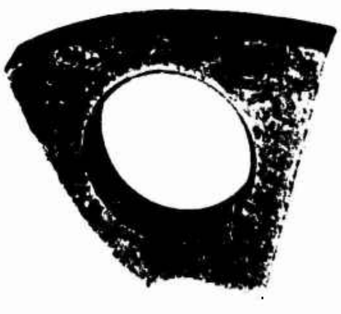


Photo Courtesy Eaton Mfg. Co.

AUTOMATIC DRYER BELT ADJUSTMENT ECCENTRIC

Here's a simple part (at least it looks simple) that falls in the class of "How else would you make it?"

The thickness and flatness specs. rule out a stamping. The hex counterbored hole and the off-center hole eliminated screw machine operations. The close tolerances of ±0.001 prevented either hot or cold forging without a secondary machining operation. Finally, the strength and wear resistance required ruled out any nonferrous metal.

Photo Courtesy Eaton Mfg. Co.

Powder metallurgy met the strength and wear resistance requirements; met the dimensional tolerances; met the flatness; and did it all without any secondary machining operations.

It's made of iron low-copper steel powder. It's not heat treated but still shows a tensile strength of 38,000 psi with 0.5% elongation. Hardness is 45 to 55 Rockwell B.

AUTOMOBILE DOOR LOCK STRIKER PLATE

One obstacle to the wider use of powder metallurgy parts is the inability to lay down a satisfactory electroplate.

The illustrated part is quite porous, but is still cadmium plated successfully. It must stand extreme wear and must be highly corrosion-resistant. These two requirements dictate a porous structure that will hold oil or grease and a material that is low in cost but still corrosion-resistant.

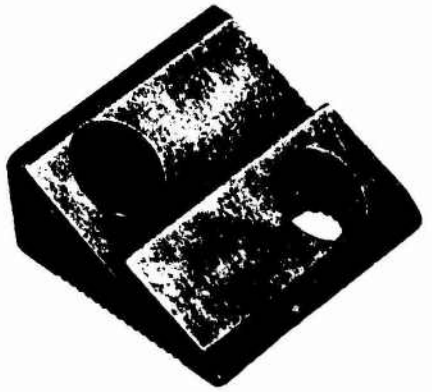


Photo Courtesy Eaton Mfg. Co.

Another outstanding advantage secured through powder metallurgy was the formation of sharp, closely dimensioned serrations in the base. By any other method of manufacture these serrations would have been machined into the striker plate.

PRINTING PRESS PAPER GRIPPER

This is a part where cost saving was most important. Used on an offset printing press, the single sheet paper gripper need only stand high wear. Strength, shock resistance, and ductility were of minor importance.

To get the wear resistance required an iron-copper alloy, infiltrated. However, the required mechanical properties (see table) were low enough so that no heat-treatment was required.

The only secondary operation was to drill one cross hole.

Application	Printing Press
Service	Light impact, high wear
Mechanical properties	75,000 psi tensile 1% elongation
Hardness (Rockwell C)	17 to 20

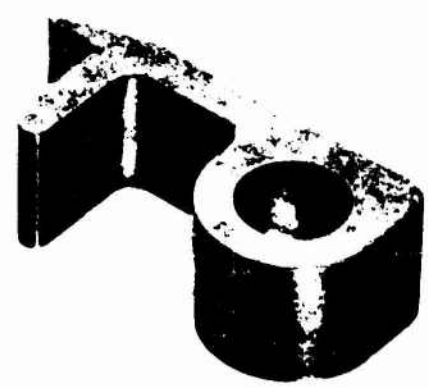


Photo Courtesy Eaton Mfg. Co.

STEEL CABLE GRIPS

The teeth on this powder metallurgy part must be hard enough to bite into high tensile strength steel alloy cables on a power transmission line support.

This was only one of the tough requirements placed on Dixon Sintaloy, Inc. when a customer asked them to make this part. The purchaser also asked that the part consistently break up into small, uniform pieces when a crimping load is applied during assembly. Dimensional requirements demanded an alloy stable enough to prevent warpage during sintering and heat treating.

An iron, copper, carbon alloy was selected with a nominal composition of .7 combined carbon and 2% copper. The part is pressed to a density of 6.4 g/cc minimum and is given a carbonitriding heat treatment.

Photo Courtesy Dixon Sintaloy, Inc.

CAM NEEDS POROSITY AND STRENGTH

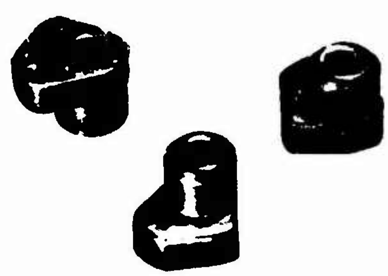
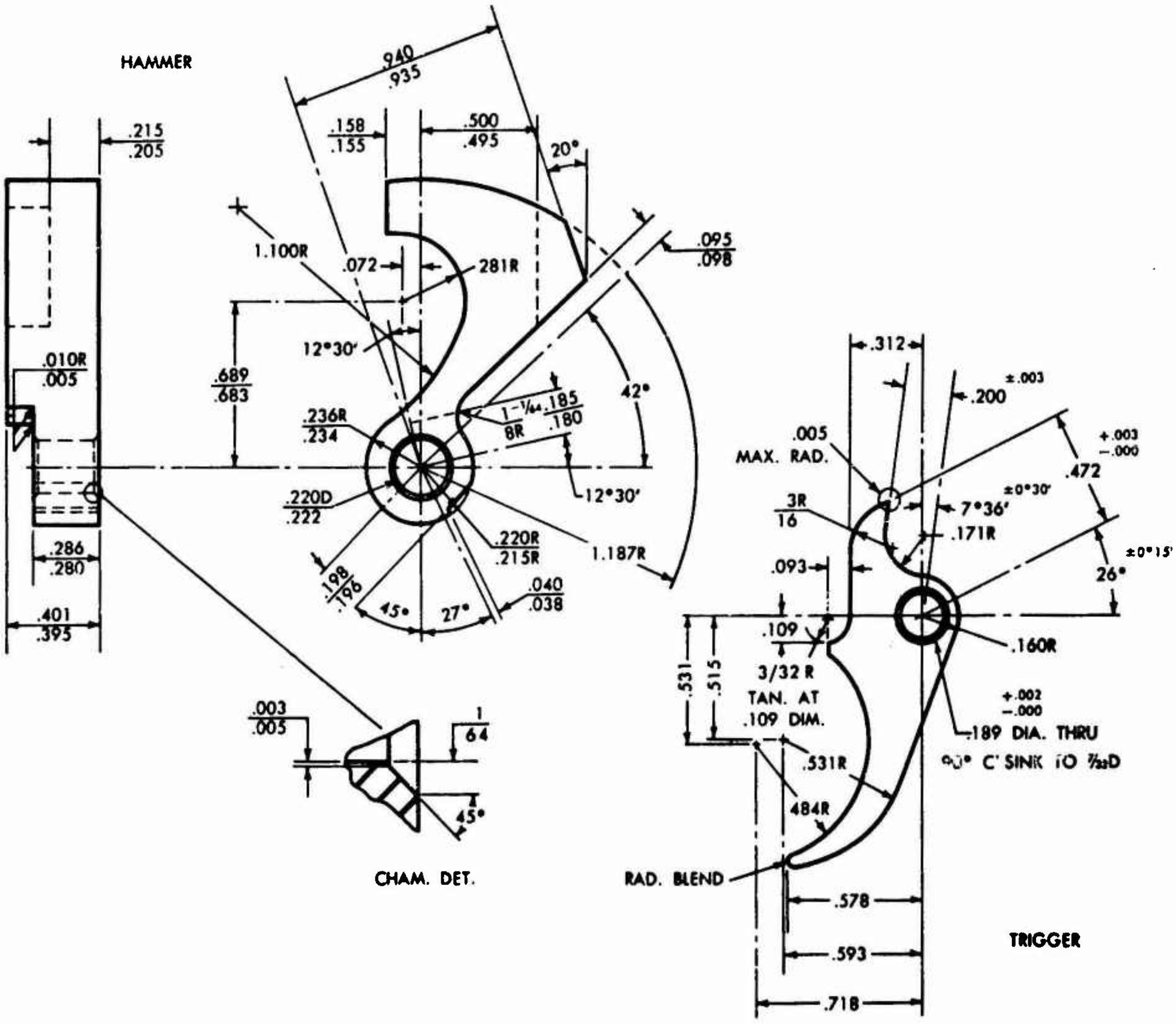


Photo Courtesy Dixon Sintaloy, Inc.

Careful consideration of material properties were necessary for a cam for a business machine. The cam needed high tensile strength and impact resistance to withstand hundreds of thousands of operating cycles without failing or brinnelling. The hole in the shank is threaded and takes a set screw which is tightened to a high torque. The part required close tolerances and a smooth surface finish. In addition, it had to have enough porosity to allow oil impregnation so that it would be self-lubricating.

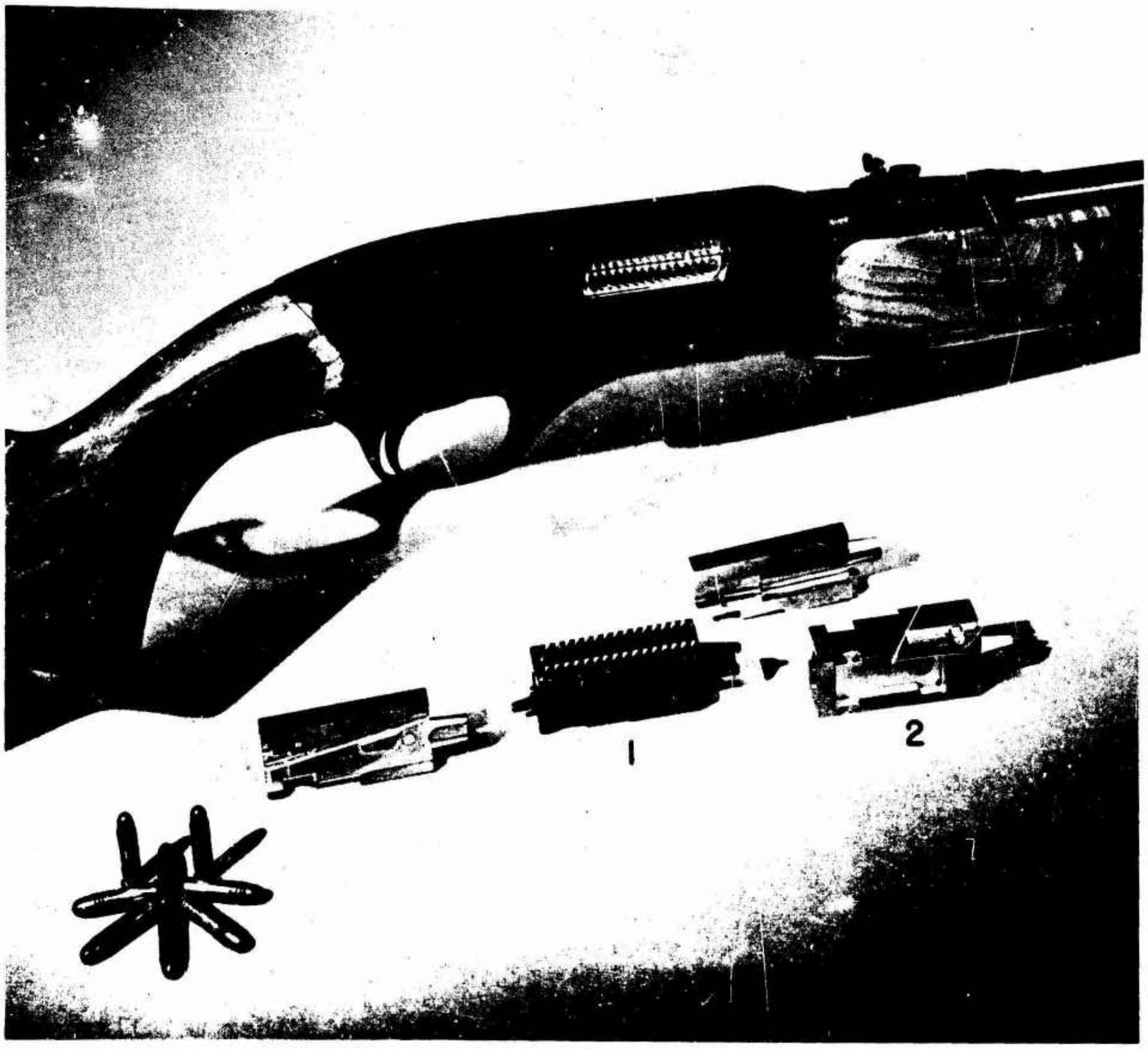
To meet these requirements, Dixon-Sintaloy, Inc. selected an alloy of iron, carbon, and copper with a nominal composition of .6 combined carbon and 7% copper. The cam has a density of 6.4 g/cc.



"The hammer was redesigned expressly for powder metallurgy as the most logical and efficient method of production. An economical method of obtaining a part with a complex configuration was needed--consequently the custom parts manufacturer was brought into the picture. He was able to demonstrate how powder metallurgy allows design freedom not possible without excessive, costly finishing operations.

"By specifying powder metallurgy, the gun manufacturer was able to provide a better product and at the same time reduce his own plant and equipment investment."

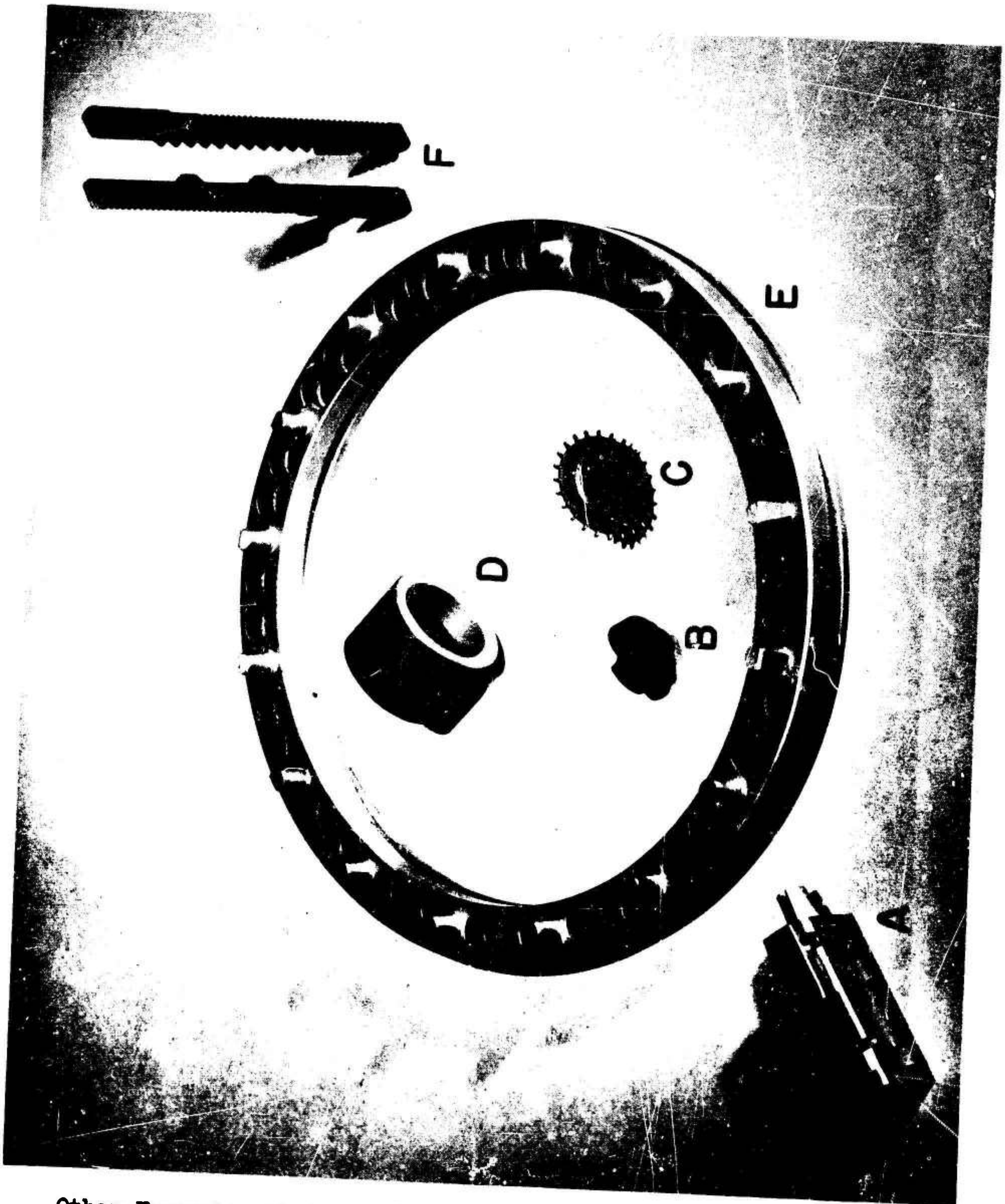
From Powder Metallurgy Quarterly, Spring 1964, Courtesy of Metal Powder Industries Federation.



" The $1,000 Grand Prize Award for the MPIF Ferrous Powder Metallurgy Part-of-the-Year went to the P/M parts manufacturer, Sintered Metals, Inc., Boston, Mass., and their customer, the Winchester-Western Div., Olin-Mathieson Chemical Corp., New Haven, Conn., for a bolt assembly used in the Winchester '200 Series' rimfire rifles."

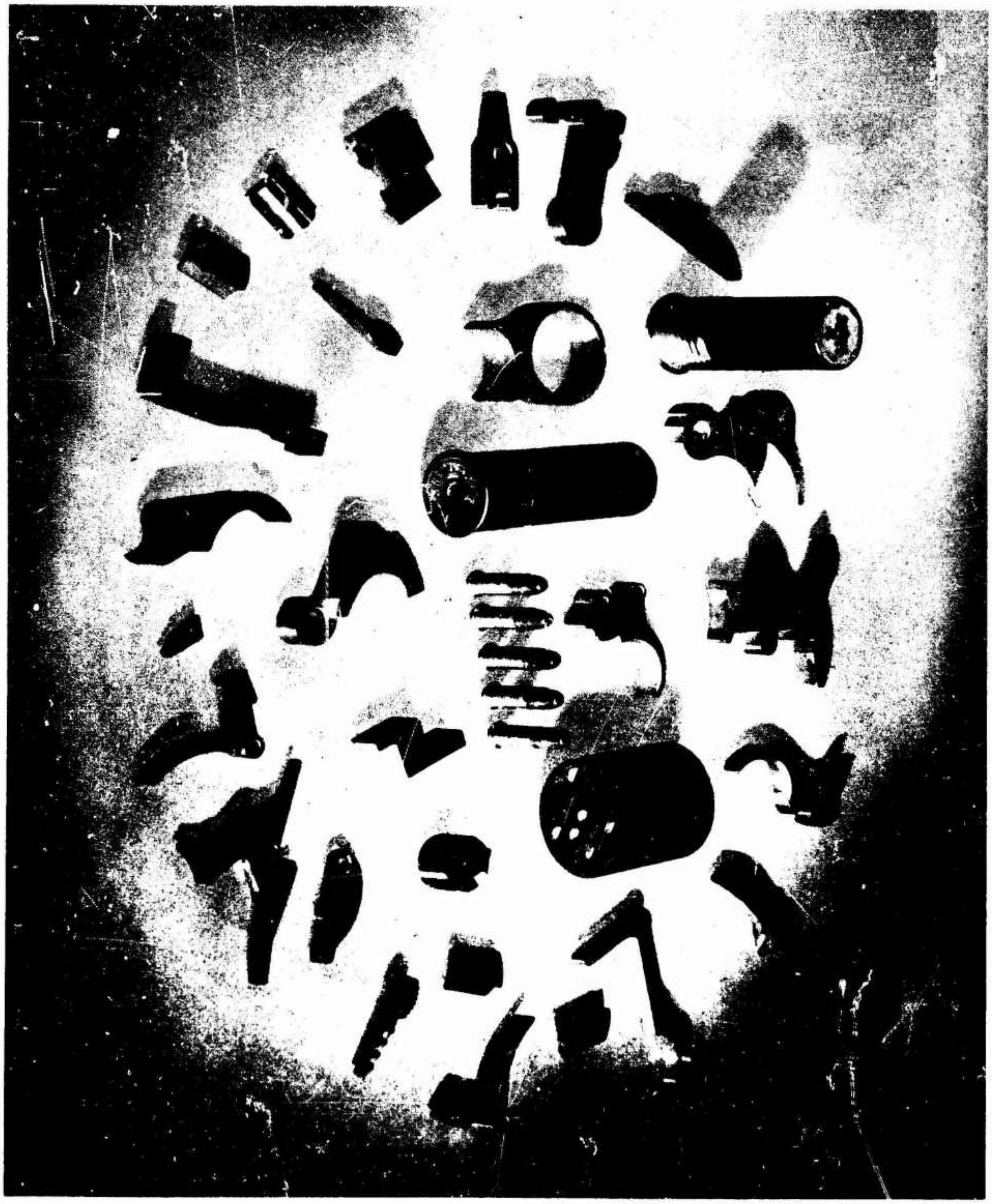
" Powder metallurgy was capable of providing a precisely engineered part with uniform physical properties, close tolerances, good surface finish and performance reliability. A costly fastening operation was eliminated by adopting projection welding of the two bolt units."

Courtesy of Metal Powder Industries Federation. Quoted text from News Release dated 10 May 1966.



Other Honorable Mention P/M parts are illustrations B through F.

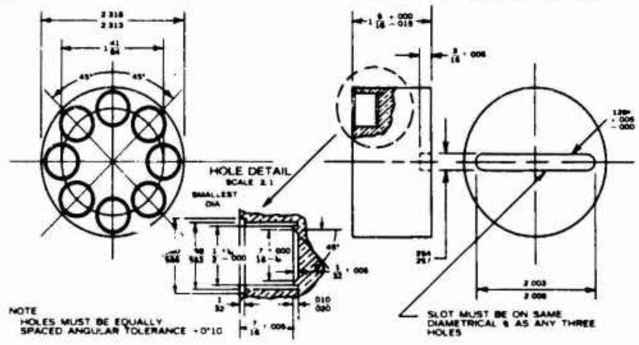
Courtesy of Metal Powder Industries Federation.



Other examples of parts produced by powder metallurgy for the sporting arms industry.

Courtesy of Metal Powder Industries Federation.

BRASS POWDER PARTS "BLOW A FUSE" WHEN AMPS GET TOO HIGH!



Electrical equipment manufacturers are now using metal powder parts in protective devices such as this component for a fuse assembly.

The brass part, especially designed for powder metallurgy, is made by Parker White Metal Company, Fairview, Pa. for Federal Pacific Electric Company, Des Plaines, Ill. Special Mention goes to Robert W. Parker of Parker White Metal and to Charles Wagner of Federal Pacific.

Each fuse assembly contains two brass cylinders which hold a number of smaller fuses. This design is necessary so that the small fuses, each complete in itself, are electrically parallel to take maximum advantage of "skin effect" which helps the fuse sense an overload or fault in the circuit.

High density is required for conductivity, strength and ductility. The strength and ductility are needed to withstand the press fit of the smaller fuses into the .553"–.558" holes. The high density also increases ease of silver soldering and final silver plating.

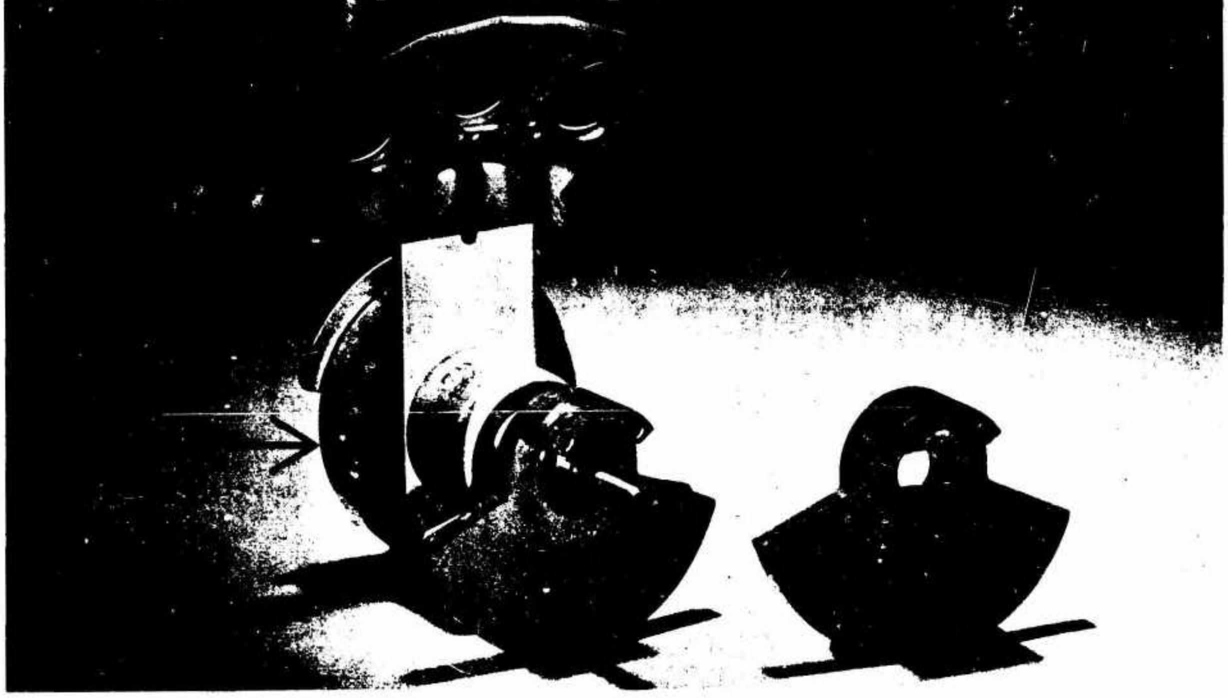
The special design problem facing the fabricator was the location of the holes in relation to each other and to the slot. The holes had to be equally spaced while the slot on the opposite surface had to be on the same diametrical centerline as any three holes (in the case of the nine hole fuse adapters shown).

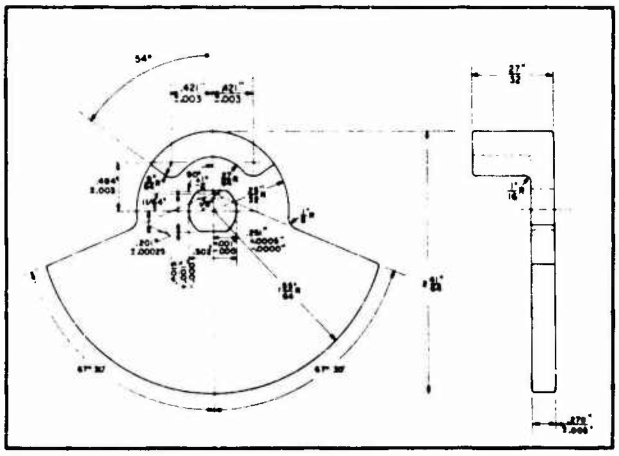
Secondary machining performed on this part is the removal of a rib on the side of the piece—used for maintaining alignment between the centerline of the slot and the centerline of the holes during fabrication. A copper blade is silver soldered in the slot at each end, then, the assembly is silver plated and encased in a melamine tube.

In reply to the question, "Why is this a metal powder part?" Federal Pacific Electric states that "It would be impractical to make any other way. If powder metallurgy had not worked, the entire fuse would have to be redesigned."

Courtesy of METAL POWDER PRESS
Vol. 14, No. 1

Nickel Silver Helps Trainmen "Keep Their Signals Straight"





Railroad operators can be sure their searchlights stay "on the beam" with the help of metal powder parts.

One such part is this nickel silver bracket used on the armature shaft of the "SA1" Searchlight Signal Housing m. de by General Railway Signal Company of Rochester, N.Y.

Previously, the part had been produced as a brass forging, requiring costly machining.

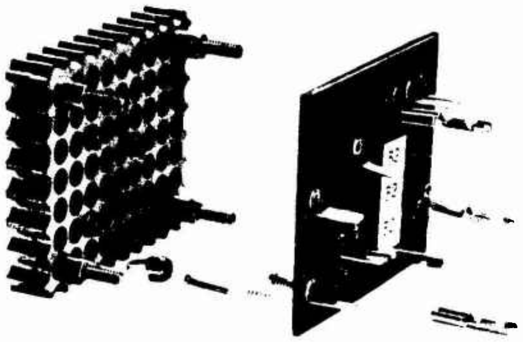
Realizing the advantages of powder metallurgy, K. J. Chase, Production Engineer at General Railway Signal, worked with Robert A. Parker of Parker White Metal Company, Fairview, Pa. to successfully produce the part from nickel silver powder—at a 40% reduction in cost! For their combined efforts, the two gentlemen received Awards of Distinction.

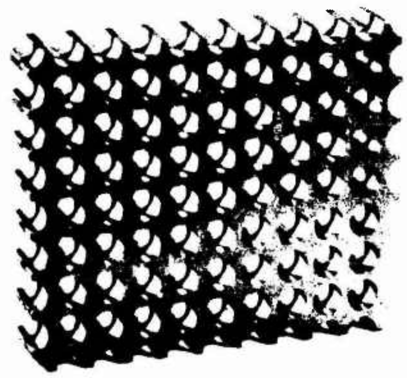
Secondary operations on the powder part consist of deburring and drilling six holes and two slots. The center hole and all other surfaces retain their smooth, precise, as-pressed surfaces.

Density of the bracket must be at least 6.9 gr/cc for weight requirements. Tolerances range from minus .0000", plus .0005" to plus or minus .003". The flat surfaces in the center hole are critical and must be precisely indexed to the limits shown in the drawing.

In addition to the prize winning bracket, the "flywheel" (see arrow in photo) is a nickel silver powdar part in this instrument.

Courtesy of METAL POWDER PRESS
Vol. 15, No. 1





These nickel silver honeycomb modules are showing signal savings for the manufacturer of a railroad control panel.

The modules hold lamps that illuminate complex track layouts in railway control towers. Tiny 3/10 watt lamps—only ⅛" in diameter—light up when track control knobs, levers and pushbuttons are operated. Each lamp has a spring loaded contact placed in a corresponding position on a contact board attached to the back of the module.

The smooth inner surfaces of the honeycomb's openings reflect the light from the tiny lamps in a concentrated area with a minimum of loss. Nickel silver's natural brightness is heightened by the burnishing action of the core rods—to provide a very reflective surface.

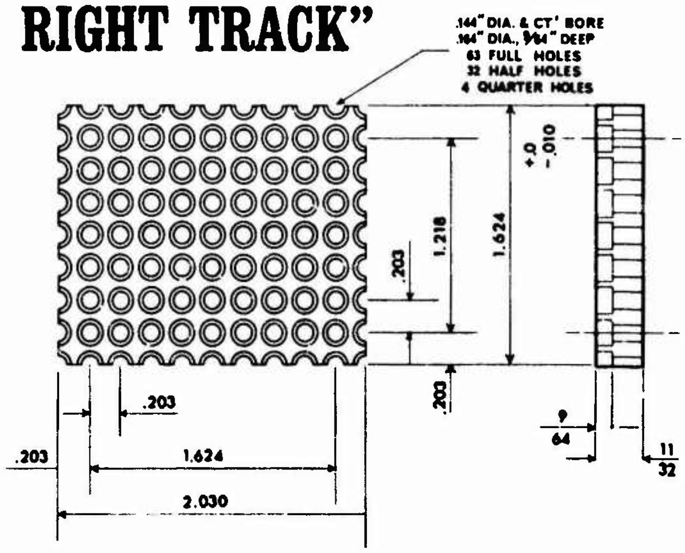
These metal powder modules can be located anywhere behind the panel, with different colored discs on the viewer's side to show track occupancy, locations of signals, route line-up, and so forth.

For the successful design and production of this unique part, K. J. Chase of General Railway Signal Company, Rochester, N. Y. and R. W. Parker of Parker White Metal Company received Awards of Distinction.

Nickel silver metal powder—a natural for this application—was the only material seriously considered by both fabricator and customer. An original design for powder metallurgy, the nickel silver module serves as a common conductor, and the holes retain very good reflectivity. A comparable machined part would cost six times more.

General Railway Signal Company says this about the part: "Powdered nickel silver is almost the only economical way of manufacturing this part. It could be machined from stainless steel or investment cast and machined from nickel silver. Any other method of retaining reflectivity would involve plating in the holes, which would be extremely difficult and costly."

NICKEL SILVER MODULES HELP TRAINS GET "ON THE RIGHT TRACK"



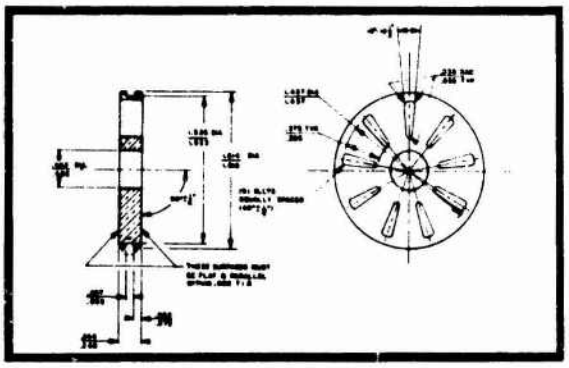
C urtesy of METAL POWDER PRESS
Vol. 13, No. 2

BRONZE VALVE PART LIKES "GETTING INTO HOT WATER"

This bronze powder valve part is always in "hot water"—and works best while in it . . . real hot water, that is!

The part is a seal plate for a hot water zone control valve. It mates with a similar graphite part to effect valve opening and closing.

Designed especially for powder metallurgy, the part was awarded Special Mention in the 1963 "Nonferrous Metal Powder Part of the Year" competition. Responsible for its successful design and production were, N. L. Benedetti of the Dole Valve Company, Morton Grove, Ill. and Nelson O. Schreiber of General Sintering Corporation, Schiller Park, Ill.



Design requirements call for stability and corrosion resistance in hot water temperature. The part must have high density (6.8 to 7.2 gr/cc) in order to obtain a lapped and polished, leakproof surface with good wear characteristics for operation with its mating part.

The seal plate's nine slots must be equally spaced at 40° plus or minus 1/4°. Rubbing surfaces must be flat and parallel within .002". Center hole diameter cannot be less than .402" or more than .403".

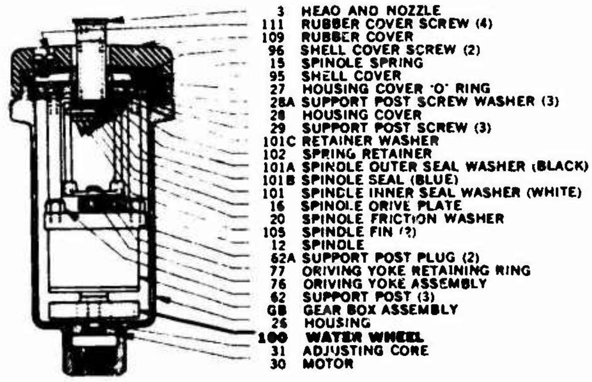
In addition to lapping and polishing, the only secondary operation performed on the part is the machining of the peripheral seal ring groove shown in the drawing.

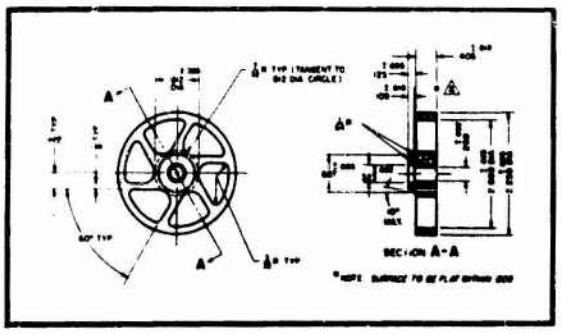
Dole Valve Company states that "after considering other methods such as forgings, castings or screw machine parts, powder metallurgy proved to be the most economical and reliable means of fabrication."

The fabricator, General Sintering Corporation, has this to say: "The Dole engineering staff involved has indicated a keen awareness of the potential of powder metallurgy in the valve industry. Together we have produced a functional part that could be fabricated on a production basis by no other method at the unit price achieved."

Courtesy of METAL POWDER PRESS
Vol. 14, No. 2

TO KEEP GRASS GREEN...sprinkle with brass powder





WELL, not quite, but the gear-driven lawn sprinklers made by the Buckner Manufacturing Company of Fresno, California do rely on an impeller or "water wheel" pressed from brass powder to provide dependable, more efficient operation.

An advantage of powder metallurgy which often is taken for granted— the exact part-to-part duplication inherent to the process—provides Buckner with a key production necessity. The sprinkler's complete gear train is water-driven by the impeller, which must turn at a fairly high rpm. Just like an automobile flywheel, this impeller must be in balance in order to do its job properly.

As originally designed and sand-cast of brass, the impeller casting was in itself economical, but considerable time, money and effort were spent by Buckner to machine each casting in order to balance it. As pressed from brass powder by Kwikset Powdered Metal Products, Anaheim, California, the impeller comes to Buckner "virtually ready for assembly." Because each part is uniform, balancing is no longer a problem. The machining operations and production delays resulting from the secondary operation required with the sand-cast part were eliminated.

The water wheel is found in several of the Buckner "Rotary Pop-Up Sprinklers," which are used for watering large turfed areas such as parks, golf courses, cemeteries and playgrounds. They are particularly in demand for use in automatically controlled sprinkling systems which operate at night and must be completely reliable. Product engineer H. M. Clark of Buckner states that "this powder metal water wheel has been one important factor in giving these sprinklers the dependability required." Naturally, brass powder was chosen for this application because of its corrosion resistance, strength and low cost.

Courtesy of METAL POWDER PRESS
Vol. 13, No. 1

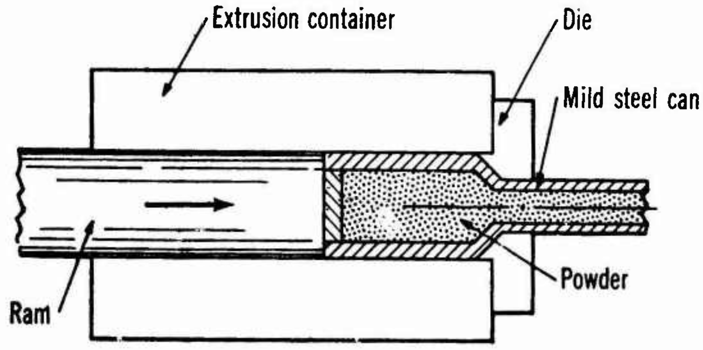


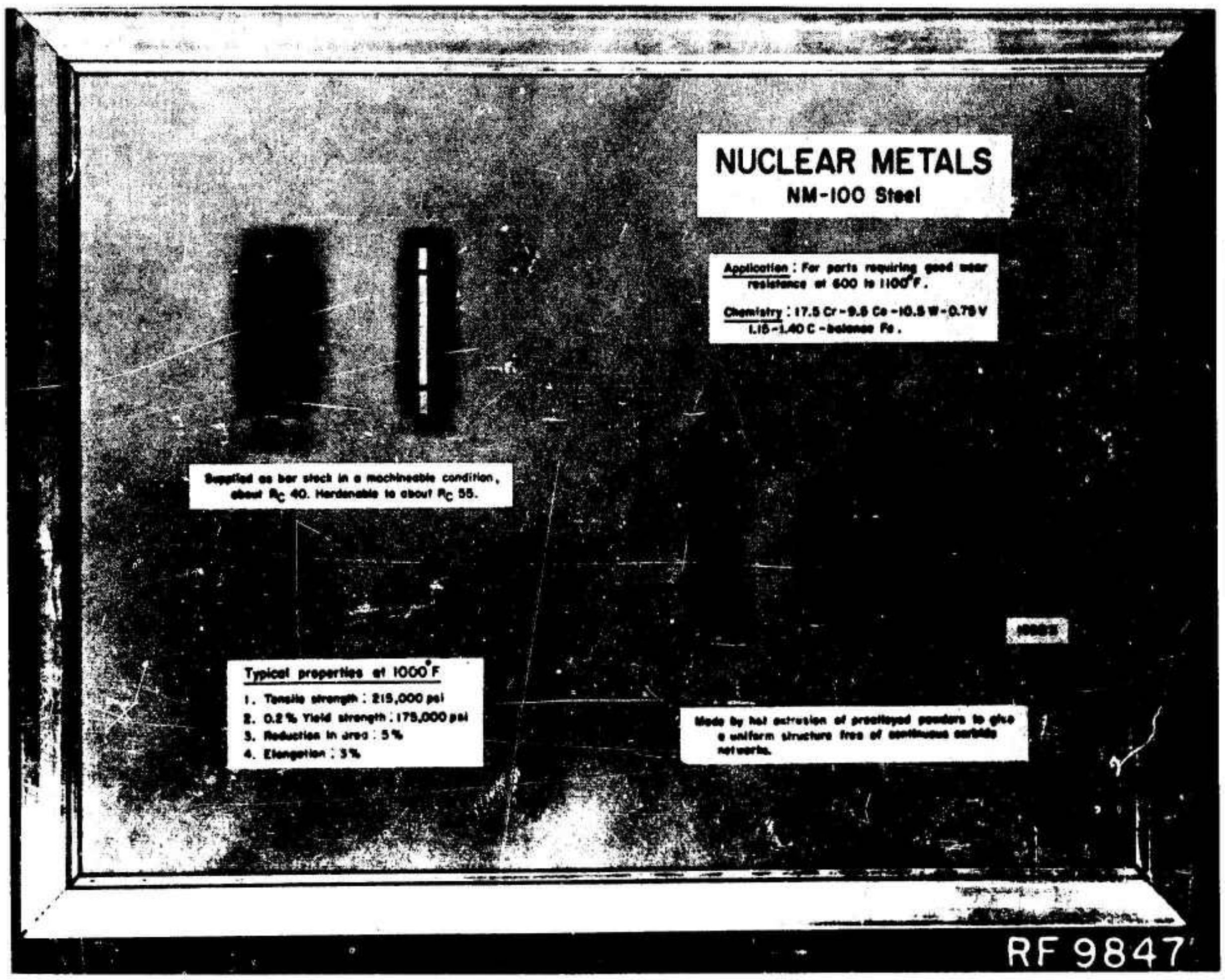
Fig. 1—Stainless steel powder of special composition, designated NM-100, is densified by canning in a steel container which is then sealed and extruded as shown. The product is equivalent to wrought material.

Extruding Bar Stock

Pre-alloyed powder, after manufacture and inspection, is packed into cans of 13 gage mild steel sheets. After the can is evacuated at room temperature to less than 0.1 microns and sealed, it can be handled like a conventional extrusion billet. The canned powder is heated to 1950 F in a reducing atmosphere (which protects the can from oxidation) and extruded at that temperature with 16 to 1 reduction ratio. Uniform cooling from the extrusion temperature is necessary to prevent cracking. The densified powder is annealed for optimum machinability by heating at 1550 F for at least 3 hr and cooled in the furnaces, not faster than 50 F per hr to 800 F or below. With a hardness of about Rockwell C 40 in the annealed condition, the alloy machines as well as high speed steels.

Table I — Mechanical Properties of NM-100

Temperature	Yield Strength	Tensile Strength	Compressive Strength	Elongation
70 F	246,000 psi	277,000 psi	275,500 psi	1.5%
600	220,000	268,500	234,000	2.0
1000	182,000	242,000	174,500	3.7
1200	79,500	111,000	70,500	11.2

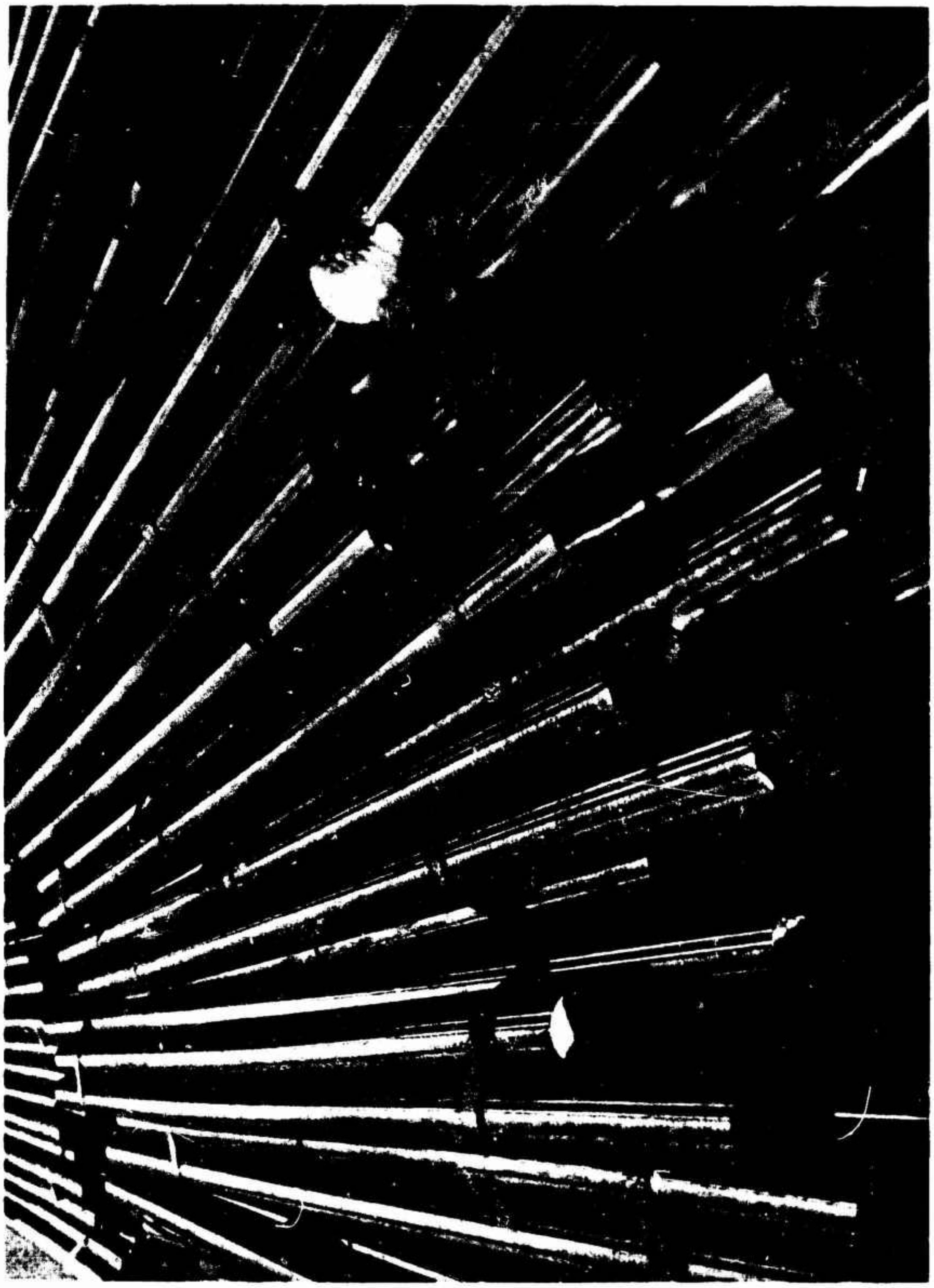


RF 9847 <u>High Temperature, High Strength Bearing Steel Produced at Nuclear Metals by Powder Metallurgy Methods</u>

NM-100 Steel is a uniformly wrought, highly alloyed martensitic steel having excellent wear and corrosion resistance at temperatures up to 1100 F. Quantity production of this alloy has been made possible by a process which includes the hot extrusion of canned, prealloyed powder. The exceptionally fine grain size and high degree of homogeneity can be obtained only by powder metallurgy methods.

(See next page)

Courtesy of Nuclear Metals Division of Textron Inc.



Courtesy of Nuclear Metals Division of Textron Inc.

Custom Makers Of Powder Metallurgy Parts

(For company addresses, see Page 64)

Company	Structural Parts (Gears, Cams, Etc.)	Electrical Parts (Contacts, Rotors, Etc.)	Filters	Self-Lubricating Bearings	Friction Materials (Clutch & Brake Linings, Etc.)	Other Parts
Adamas Carbide Corp.						X
Allied Sinterings Inc.	X	X	X	X	X	X
Aluminum Co. of America	X					X
American Brake Shoe Co.					X	
American Powdered Metals Inc.	X	X	X	X	X	[illegible]
Arnold Engineering Co.		X				X
Arrow Sintered Products Co.	X		X			
Asco Sintering Corp.	X	X	X	X	X	
Bassick Co.	X	X	X	X		X
Beemer Engineering Co.				X		
Belmont Smelting & Refining Works Inc.						X
Bendix Corp., Marshall-Eclipse Div.					X	
Bound Brook Bearing Corp.	X			X		
Brockway Pressed Metals Inc.	X	X	X	X		
Bunting Brass & Bronze Co.	X	X	X	X		X
Burgess-Norton Mfg. Co.	X		X	X		
Carbon City Products Co. Inc.	X	X		X		
Ceromet Inc.	X	X		X		X
Chicago Powdered Metal Products Co.	X	X		X		X
Chromalloy Corp., Sintercast Div.	X					X
Chrysler Corp., Amplex Div.	X	X	X	X	X	X
Cleveland Powder Metal Co. Inc.	X	X	X	X		
Cleveland Tungsten Inc.		X				X
Clevite Corp.	X		X	X		X
Compacted Metals Corp.	X	X	X	X		X
Detroit Aluminum & Brass Corp.						X
Deva Metal Corp.				X		
Dixon Sintaloy Inc., Subs. Joseph Dixon Crucible Co.	X	X	X	X		X
Eaton Mfg. Co., Powdered Metals Div.	X	X		X	X	
Elco Sintered Alloys Co. Inc.	X			X		X
Engineered Sinterings & Plastics Inc.	X	X				X
Fansteel Metallurgical Corp.	X	X				X
Ferraloy Inc.	X	X		X		X
Firth Sterling Inc.	X	X				X
General Electric Co., Lamp Metals & Components Dept.		X				X
General Electric Co., Metallurgical Products Dept.	X					X
General Metals Powder Co.					X	
General Motors Corp., Delco Moraine Div.	X	X	X	X	X	
General Sintering Corp.	X		X	X	X	
Gibson Electric Co.		X	X			
Globe Industries Inc., Supermet Div.	X	X				
Graphite Metallizing Corp.		X		X	X	

Company	Structural Parts (Gears, Cams, Etc.)	Electrical Parts (Contacts, Rotors, Etc.)	Filters	Self-Lubricating Bearings	Friction Materials (Clutch & Brake Linings, Etc.)	Other Parts
Haller Inc.	X	X		X		X
Indiana General Corp., Magnet Div.		X				
International Powder Metallurgy Co. Inc.	X	X	X	X	X	X
Kennametal Inc.	X					X
Keystone Carbon Co.	X	X	X	X		
Kulite Tungsten Co.	X					X
Kwikset Powdered Metal Products	X	X	X	X	X	X
Link-Belt Co.	X					
Magnetic Core Corp.		X				X
Magnetic Metals Co.		X				
P. R. Mallory & Co. Inc., Mallory Metallurgical Co. Div.	X	X		X		X
A. B. McMahan Co.	X		X	X		X
Merriman Bros. Inc.	X	X				X
Metal Ceramics Powdered Metal Products	X	X	X	X	X	X
Metal Powder Products Inc.	X	X	X	X		X
MicroMetals		X				
Midwest Sintered Products Corp.	X					
MK Diamond Products						X
Mott Metallurgical Corp.			X			X
Mueller Brass Co.	X	X	X	X		
Muskegon Piston Ring Co., Sparta Foundry Div.	X					X
National Molded Products Inc.	X	X	X	X		X
National Moldite Co. Inc.		X				X
Pacific Sintered Metals Co.	X	X	X	X		
Pall Corp.			X			
Panoramic Corp., Sintered Specialties Div.		X	X			X
Parker White Metal Co.	X	X	X	X	X	
Permanent Filter Corp.			X			
Perth Metal Industries Ltd.	X		X	X		
Philips Elmet Corp.		X				X
Picco Industries	X	X	X	X	X	
Powder Alloys Corp.	X					X
Powdercraft Corp.	X		X	X	X	X
Precision Metal Products Co.	X		X	X		
Presmet Corp.	X					
Purolator Products Inc.			X			
Pyroferric Co. Inc.		X				X
Quality Components Inc.		X				X
Raybestos-Manhattan Inc., Raybestos Div.					X	
Raybestos-Manhattan Inc., Wabash Div.					X	
Reese Metal Products Corp.	X	X		X		

December 2, 1963

Custom Makers Of Powder Metallurgy Parts (continued)

(For company addresses, see Page 64)

	Structural Parts (Gears, Cams, Etc.)	Electrical Parts (Contacts, Rotors, Etc.)	Filters	Self-Lubricating Bearings	Friction Materials (Clutch & Brake Linings, Etc.)	Other Parts
Robertshaw Controls Co., Lux Time Div.	X	X				
Rocky Mountain Metals Div. Inc.	X	X		X		X
Romanoff Co.	X	X	X	X		X
Russell, Burdsall & Ward Bolt & Nut Co., Sintered Products Div.	X	X	X	X	X	
St. Marys Carbon Co.	X	X	X	X		
Sherritt Gordon Mines Ltd.						X
Shwayder Chemical Metallurgy Corp.					X	
Sintered Metals Inc.	X	X	X			X
Speer Carbon Co.		X				
Stackpole Carbon Co.		X				X
Sterling Engineering Corp.	X	X		X		
Superior Carbon Products Inc.	X	X				
Sylvania Electric Products Inc., Chemical & Metallurgical Div.		X				
Sylvania Electric Products Inc., Sylcor Div.						X
Symmco Inc.	X			X		
Technametals Inc.	X	X	X			X
Union Carbide Corp., Stellite Div.						X
Vermont American Corp., Multi Metals Inc. Div.						X
Wakefield Bearing Corp.	X	X	X	X	X	X
Welded Carbide Co. Inc.	X		X			X
S. K. Wellman Co.					X	
Western Sintering Co.	X		X	X		X
Wickes Corp., United States Graphite Co. Div.	X	X		X		X
Zenith Sintered Products	X	X		X		

Suppliers Of Metal Powders

(For company addresses, see Page 64)

	Iron	Stainless Steel	Pre-blends & Special Alloys With Iron Base	Copper	Brass	Bronze	Other Copper Base Alloys	Nickel & Nickel Base Alloys	Aluminum & Aluminum Base Alloys	Beryllium	Chromium	Cobalt	Lead	Molybdenum	Precious Metals	Tantalum	Tin	Titanium	Tungsten	Other Special Alloys
Adamas Carbide Corp.																				X
Alan Wood Steel Co.	X		X																	
Allis-Chalmers Mfg. Co., Cerac Section, New Products Dept.	X	X	X	X	X	X		X	X		X	X	X	X		X	X	X	X	
Aluminum Co. of America									X											
Associated Engineering & Mfg. Corp.														X					X	X
Atlantic Powdered Metals Inc.				X	X	X	X		X											
Belmont Smelting & Refining Works Inc.	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X
Beryllium Corp.										X										
Paul Blum Co.	X																		X	
Bram Metallurgical-Chemical Co.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Brush Beryllium Co.							X			X										
Cleveland Tungsten Inc.														X					X	
Climax Molybdenum Co. of Michigan														X					X	
Consolidated Astronautics Inc.		X					X	X			X			X		X		X	X	X
Core-Tronics Inc.	X																			
Domtar Chemicals Ltd., Metal Powders Div.	X	X	X																	
Easton Metal Powder Co.	X		X																	
Elco Sintered Alloys Co. Inc.	X		X	X		X	X													
Engelhard Industries Inc., Magna Div.				X	X		X		X						X					
Fansteel Metallurgical Corp.				X			X							X	X	X			X	X

SUPPLIERS OF METAL POWDERS (continued)	Iron	Stainless Steel	Pre-blends & Special Alloys With Iron Base	Copper	Brass	Bronze	Other Copper Base Alloys	Nickel & Nickel Base Alloys	Aluminum & Aluminum Base Alloys	Beryllium	Chromium	Cobalt	Lead	Molybdenum	Precious Metals	Tantalum	Tin	Titanium	Tungsten	Other Special Alloys
Federal-Mogul-Bower Bearings Inc., Federal-Mogul Div.	X	X	X	X	X	X	X	X	X			X	X		X		X			X
Firth Sterling Inc.																			X	X
Foote Mineral Co.			X								X									X
Freeman Corp.	X		X																	
General Aniline & Film Corp., Dyestuff & Chemical Div.	X																			
General Electric Co., Lamp Metals & Components Dept.														X					X	
Glidden Co.	X	X	X	X	X	X	X	X			X	X	X				X			X
Greenback Industries Inc.				X	X	X	X													X
Handy & Harman															X					
Charles Hardy Inc.	X	X	X	X	X	X	X	X	X		X	X	X	X		X	X	X	X	X
Hoeganaes Sponge Iron Corp.	X	X	X					X												X
O. Hommel Co.								X				X			X		X			X
Indiana Copper Corp.				X																
Industeel Co.	X																			
International Nickel Co. Inc.	X							X												
A. Johnson & Co. Inc.	X		X																	X
Kennametal Inc.																X		X	X	X
Kulite Tungsten Co.												X		X					X	
M & R Refractory Metals Inc.											X			X					X	
P. R. Mallory & Co. Inc., Mallory Metallurgical Co. Div.																			X	
Malone Metal Powders				X																
Metal Hydrides Inc.								X										X		X
Metallurg Inc., Shieldalloy Corp. Subs.								X	X		X			X		X		X	X	X
Metallurgical International Inc.														X		X			X	
Metals Disintegrating Corp.				X		X			X		X		X				X	X		
Metz Refining Co.							X								X					
Monsanto Chemical Co., Inorganic Chemicals Div.				X																
National Lead Co.													X							
New Jersey Zinc Co.				X	X	X	X	X												
Chas. Pfizer & Co. Inc., C. K. Williams & Co. Div.		X	X																	X
Philips Elmet Corp.														X					X	
Pyroferric Co. Inc.	X																			
Pyron Co., Div. of American Metal Climax Inc.	X		X																	
Reynolds Metals Co.									X											
J. A. Samuel & Co. Inc.															X					
Sherritt Gordon Mines Ltd.								X				X								
Shwayder Chemical-Metallurgy Corp.	X																		X	
Sylvania Electric Products Inc., Chemical & Metallurgical Div.														X					X	
C. Tennant, Sons & Co. of New York			X				X	X			X			X		X			X	X
Thermal Dynamics Corp.								X		X	X	X		X		X		X	X	X
Union Carbide Corp., Stellite Div.			X					X												X
United Mineral & Chemical Corp.	X			X				X	X	X	X	X	X	X	X	X	X	X	X	
United States Bronze Powders Inc.				X	X	X	X	X	X											X
United States Metals Refining Co., Div. of American Metal Climax Inc.				X		X	X								X		X			X
Uniworld Research Corp. of America			X					X												X
Valley Metallurgical Processing Co.				X	X	X	X		X	X										X
Wah Chang Corp.														X		X			X	
Welded Carbide Co. Inc.	X	X	X	X				X			X	X							X	

December 2, 1963

Addresses Of Makers Of Powder Metallurgy Parts And Suppliers Of Metal Powder

Ademas Carbide Corp. ....Kenilworth, N. J.
Alan Wood Steel Co. ....Conshohocken, Pa.
Allied Sinterings Inc. ....65 Sugar Hollow Rd., Denbury, Conn.
Allis-Chalmers Mfg. Co., Carec Section,
  New Products Dept. ....P. O. Box 512, Milweukee, Wis. 53201
Aluminum Co. of America ....1501 Alcoa Bldg., Pittsburgh, Pe. 15219.
American Breke Shoe Co. ....5372 W. 130th St., Cleveland, Ohio 44142.
American Powdered Metals Inc. ....7 Philip Place, North Neven, Conn.
Arnold Engineering Co. ....P. O. Box "G," Marengo, Ill.
Arrow Sintered Producta Co. ....2727 S. 18th Ava., Broadview, Ill.
Asco Sintering Corp. ....7799 Telegraph Rd., Los Angeles, Calif. 90022.
Associated Engineering & Mfg. Corp. ....Glen Ridge, N. J.
Atlantic Powdered Metals Inc. ....38 Park Row, New York, N. Y. 10038.

Baasick Co. ....960 Atlantic St., Bridgeport, Conn. 06602.
Beemer Engineering Co. ....Industrial Park, Ft. Washington, Pe.
Balmont Smelting & Refining Works Inc.
  ....330 Belmont Ave., Brooklyn, N. Y. 11207.
Bendix Corp., Mershall-Eclipse Div. ....P. O. Box 238, Troy, N. Y.
Beryllium Corp. ....Reading, Pe.
Peul Blum Co. ....315 Larkin St., Buffelo, N. Y. 14210.
Bound Brook Bearing Corp. ....Lincoln Boulevard, Bound Brook, N. J.
Bram Metallurgical-Chemical Co. ....820—65th Ave., Philadelphia, Pa. 19126.
Brockway Pressed Metals Inc. ....921 Clerk St., Brockway, Pa. 15824.
Brush Beryllium Co. ....17876 St. Clair Ava., Clevelend, Ohio 44110.
Bunting Brass & Bronze Co. ....715 Spencer St., Toledo, Ohio 43601.
Burgess-Norton Mfg. Co. ....737 Peyton St., Geneve, Ill. 60134.

Carbon City Products Co. Inc. ....Ford Road, St. Merys, Pe.
Ceromet Inc. ....16233 Gale Ave., Industry, Calif.
Chicago Powdered Metel Products Co. ....9700 Wavelend Ave., Schiller Perk, Ill.
Chromalloy Corp., Sintercast Div.
  ....169 Western Nighway, West Nyeck, N. Y. 10994.
Chrysler Corp., Amplex Div. ....P. O. Box 2718, Detroit, Mich. 48231.
Clevaland Powder Metel Co. Inc. ....320 S. Weter St., Kent, Ohio.
Clevelend Tungsten Inc. ....10200 Meech Ave., Cleveland, Ohio 44105.
Clevite Corp. ....17000 St. Clair Ava., Clevaland, Ohio 44110.
Climax Molybdenum Co. of Michigen
  ....14410 Woodrow Wilson, Detroit, Mich. 48238.
Compacted Metels Corp. ....99 Greenwood Ava., Waukegan, Ill.
Consolidated Astroneutics Inc.
  ....41-45 Crascant St., Long Island City, N. Y. 11101.
Core-Tronics Inc. ....241 N. Dey St., Orange, N. J.

Detroit Aluminum & Bress Corp. ....3975 Christopher, Detroit, Mich. 48211.
Deve Metal Corp. ....225 Ellison St., Paterson, N. J. 07501.
Dixon Sintaloy Inc., subsidiary of
  Joseph Dixon Crucible Co. ....535 Nope St., Stemford, Conn.
Domtar Chemicals Ltd., Metal Powders Div.
  ....1155 Dorchastar St. W., Montreel, Que., Cenede

Easton Metal Powder Co. ....900 Line St., Easton, Pa.
Eaton Mfg. Co., Powdered Metels Div. ....325 Jay St., Coldwater, Mich.
Elco Sintered Alloys Co. Inc. ....Box 486, St. Merys, Pe.
Engelhard Industries Inc., Magna Div. ....Fourth Avenue, Heskall, N. J.
Engineered Sinterings & Plastics Inc. ....P. O. Drawer P, Watertown, Conn.

Fansteel Metallurgical Corp. ....North Chicago, Ill.
Federal-Mogul-Bower Bearings Inc.,
  Federal-Mogul Div. ....2310 S. Industrial Nighway, Ann Arbor, Mich. 48106.
Ferroloy Inc. ....W. Merket Street, Salem, Ind.
Firth Sterling Inc. ....3113 Forbes Ave., Pittsburgh, Pe. 15230.
Foote Minerel Co. ....Route 100, Exton, Pa.
Freeman Corp. ....P. O. Box 85, Cap-de-la-Madeleine, Que., Canada

General Aniline & Film Corp.,
  Dyestuff & Chemical Div. ....435 Nudson St., New York, N. Y. 10014.
General Electric Co., Lamp Metals &
  Components Dept. ....21800 Tungsten Rd., Cleveland, Ohio 44117.
General Electric Co., Metallurgical
  Products Dept. ....11177 E. Eight Mile Rd., Detroit, Mich. 48232.
Genarat Metals Powder Co. ....130 Elinor Ava., Akron, Ohio 44305.
General Motors Corp., Delco Moraine Div.
  ....1420 Wisconsin Blvd., Deyton, Ohio 45401.
General Sintering Corp. ....3907 Wesley Terrace, Schiller Perk, Ill.
Gibson Electric Co. ....Old William Penn Nighway, Delmont, Pa.
Glidden Co. ....900 Union Commerce Bldg., Cleveland, Ohio 44114.
Globe Industries Inc., Supermet Div. ....1460 Cincinnati St., Deyton, Ohio 45408.
Graphite Metallizing Corp. ....1050 Nepperhan Ava., Yonkers, N. Y.
Greenback Industries Inc ....2527 W. Maple Rd. Birmingham, Mich.

Naller Inc. ....16580 Northville Rd., Northville, Mich.
Handy & Harman ....850 Third Ava., New York, N. Y. 10022.
Cherles Herdy Inc. ....420 Lexington Ave., New York, N. Y. 10017.
Hoeganaes Sponge Iron Corp. ....River Road & Taylor Lane, Riverton, N. J.
D. Hommel Co ....Hope & Maple Streets, Carnegie, Pa. 15106.

Indiana Copper Corp ....666 Lincoln Blvd., Merion, Ind. 46953.
Indiana General Corp., Magnat Div. ....405 Elm St., Valparaiso, Ind.
Industeel Co. ....P. O Box 4025, Pittsburgh, Pe. 15201.
International Nickel Co. Inc ....67 Wall St., New York, N. Y. 10005.
International Powder Metallurgy Co Inc. ....439 W. Mein St., Ridgway, Pa.

A. Johnson & Co. Inc. ....21 West St., New York, N. Y. 10006.

Kennametal Inc. ....Lloyd Avenue, Latrobe, Pa.
Keystone Carbon Co. ....State Street, St. Merys, Pa.
Kulite Tungsten Co. ....1040 Hoyt Ave., Ridgefield, N. J.
Kwikset Powdered Metal Products ....516 E. Sante Ana St., Anaheim, Calif.

Link-Belt Co. ....220 S. Belmont Ave., Indianapolis, Ind.

M&R Refractory Metals Inc. ....65 Brown Ave., Springfield, N. J. 07081.
Magnetic Core Corp. ....P. O. Box 368, Newburgh, N. Y. 12553.
Magnetic Metals Co. ....Heyes Avenue at 21st Street, Camden, N. J.
P. R. Mallory & Co. Inc., Mallory
  Metallurgical Co. Div. ....3029 E. Washington St., Indianapolis, Ind.
Malone Metal Powders ....Flemington, N. J.
A. B. McMahan Co. ....693 Reymond Ave., St. Paul, Minn. 55114.
Merriman Bros. Inc. ....185 Amory St., Boston, Mess. 02130.
Metal Ceramics Powdered Metel Products ....1511 Mennheim Rd., Stone Perk, Ill.
Metal Hydrides Inc. ....12-24 Congress St., Beverly, Mass.
Metallurgical International Inc. ....121 Howe Ava., Passaic, N. J.
Metal Powder Products Inc. ....P. O. Box 189, Logan, Ohio.
Metals Disintegrating Corp. ....P. O. Box 290, Elizabeth, N. J. 07207.
Matz Refining Co. ....369 Mulberry St., Newark, N. J. 07102.
MicroMetals ....72 E. Montecito Ava., Sierra Madre, Calif. 91024.
Midwest Sintered Products Corp. ....13605 S. Halsted St., Chicago, Ill. 60627.
MK Diamond Products ....12600 Chadron, Hawthorne, Calif.
Monsanto Chemical Co., Inorganic
  Chemicals Div. ....800 N. Lindberg Blvd., St. Louis, Mo. 63166.
Mott Metallurgical Corp. ....272 Huyshope Ave., Hartford, Conn. 06114.
Mueller Brass Co. ....1925 Lapeer Ave., Port Huron, Mich. 48061.
Muskegon Piston Ring Co., Sparta Foundry Div. ....Sparta, Mich.

National Lead Co. ....111 Broadway, New York, N. Y. 10006.
National Molded Products Inc. ....40-42 S. St. Marys St., St. Marys, Pa.
National Moldite Co. Inc. ....250 South St., Newark, N. J. 07114.
New Jersey Zinc Co. ....160 Front St., New York, N. Y. 10038.

Pacific Sintered Metals Co. ....16120 S. Figueroa St., Gardena, Calif.
Pall Corp. ....30 Sea Cliff Ave., Glen Cove, N. Y.
Penoramic Corp., Sintered Specialties Div.
  ....1450 Riverside St., Janesville, Wis. 53546.
Parker White Metal Co.
  ....P. O. Box 276, U. S. Route 20, Fairview, Erie County, Pa.
Permanent Filter Corp. ....18744 S. Reyes St., Compton, Calif.
Perth Metal Industries Ltd.,
  ....128 Monteith, P. O. Box 154, Stratford, Ont., Canada.
Chas. Pfizer & Co. Inc.,
  C. K. Williams & Co. Div. ....235 E. 42nd St., New York, N. Y. 10017.
Philips Elmet Corp. ....Lisbon Road, Lewiston, Maine
Picco Industries ....1729 N. Chico Ava., El Monte, Calif.
Powder Alloys Corp. ....820 Bloomfield Ave., P. O. Box 825, Clifton, N. J. 07013.
Powdercraft Corp. ....P. O. Box 1772, Spartanburg, S. C.
Precision Metal Products Co. ....P. O. Box 129, Ellwood City, Pa.
Presmet Corp. ....112 Harding St., Worcester, Mass. 01604.
Purolator Products Inc. ....270 New Brunswick Ava., Rahway, N. J.
Pyrofarric Co. Inc. ....621 E. 216th St., New York, N. Y. 10067.
Pyron Co., Div. of American Metal Climax Inc.
  ....P. O. Box E, Laselle Station, Niagara Falls, N. Y. 14304.

Quality Components Inc. ....P. O. Box 113, St. Marys, Pa.

Raybestos-Manhattan Inc., Raybestos Div.
  ....P. O. Box 1021, Bridgeport, Conn. 06601.
Raybestos-Manhattan Inc., Wabash Div.
  ....1202 Darlington Ava., Crawfordsville, Ind. 47933.
Reese Metal Products Corp. ....P. O. Box 480, Lancaster, Pa.
Reynolds Metals Co. ....Reynolds Metals Bldg., Richmond, Va. 23218.
Robertshaw Controls Co., Lux Time Div.
  ....95 Johnson St., Waterbury, Conn. 06720.
Rocky Mountain Metals Div. Inc.
  ....Box 1591, 3200 N. Century Ave., Colorado Springs, Colo.
Romanoff Co. ....710 Pleasant St., Rochdale, Mass.
Russell, Burdsall & Ward Bolt & Nut Co.,
  Sintered Products Div. ....Midland Avenue, Port Chester, N. Y.

J. A. Samuel & Co. Inc. ....165 Broadway, New York, N. Y.
St. Marys Carbon Co. ....State Street, St. Marys, Pa. 15857.
Sherritt Gordon Mines Ltd. ....25 King St., W., Toronto 1, Ont., Canada.
Shieldalloy Corp., subsidiary Metallurg Inc. ....West Boulevard, Newfield, N. J.
Shwayder Chemical Metallurgy Corp.
  ....684 E. Woodbridge St., Detroit, Mich. 48226.
Sintered Metals Inc. ....P. O. Box 56, Boston, Mass. 02130.
Speer Carbon Co. ....Tnarasie Street, St. Marys, Pa. 15857.
Stackpole Carbon Co. ....Stackpole Street, St. Marys, Pa.
Starling Engineering Corp. ....Hartford-Winsted Road, Winsted, Conn.
Superior Carbon Products Inc. ....9115 George Ave., Cleveland, Ohio 44105.
Sylvania Electric Products Inc., Chemical &
  Metallurgical Div. ....Towanda, Pa. 18848.
Sylvania Electric Products Inc., Sylcor Div. ....Cantiague Road, Hicksville, N. Y.
Symmco Inc. ....P. O. Box F, Sykesville, Pa. 15865.

Technametals Inc. ....R. D. #1, Box 48, Johnson Road, Pitcairn, Pa.
C. Tennant, Sons & Co., of New York
  ....100 Park Ava., New York, N. Y. 10017.
Thermal Dynamics Corp. ....213 Mechanic St., Lebanon, N. H.

Union Carbide Corp., Stellite Div. ....1020 W. Park Ava., Kokomo, Ind.
United Mineral & Chemical Corp ....16 Hudson St., New York, N. Y. 10013.
United States Bronze Powders Inc. ....P. O. Box 31, Flemington, N. J. 08822.
United States Metals Refining Co., Div. of American Metal Climax Inc.
  ....1270 Avenue of the Americas, New York, N. Y. 10020.
Uniworld Research Corp. of America
  ....12000 Shaker Blvd., Cleveland, Ohio 44120.

Valley Metallurgical Processing Co. ....Essex, Conn.
Vermont American Corp., Multi Metals Inc. Div.
  ....500 E. Main St., Louisville, Ky. 40202.

Wah Chang Corp. ....100 Church St., New York, N. Y. 10007
Wakefield Bearing Corp. ....29 Foundry St., Wakefield, Mass.
Welded Carbide Co. Inc. ....68 Colfax Ave., Clifton, N. J.
S. K. Wellman Co. ....200 Egbert Rd., Bedford, Ohio
Western Sintering Co. ....1419 Potter, Richland, Wash. 99352.
Wickes Corp., United States Graphite Co. Div.
  ....1621 Holland Ave., Saginaw, Mich. 48605.

Zenith Sintered Products ....W. 13466 Reichert Ava., Menomonee Falls, Wis.

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4. Conclusion: The main conclusions arising from this review are as follows:

a. The powder metallurgy technique is a manufacturing process.

b. Powder metallurgy techniques can be definitely applied to U. S. Army materiel.

c. Powder metallurgy has demonstrated economic and unusual material capabilities beyond some conventional methods and fabrication techniques which are presently utilized for the manufacture of Army materiel.

d. The current level of activity indicates the powder metallurgy technique is an economic and useful process and promises to open up areas where it once was thought it would not be utilized because of limited mechanical properties in the P/M fabricated part.

e. The actual potential of the powder metallurgy process surface has only been scratched and it remains to be developed and utilized to its fullest capability.

f. Powder metallurgy fabrication work should be performed by industrial sources which have the successful experience, equipment, and laboratory backup where extraordinary properties and characteristics are required for the structural part.

g. The powder metallurgy process is subject to limitations much the same as with any other manufacturing process. But the healthy activity in the area indicates that quite a few of these limitations will be reduced or eliminated.

5. Recommendations:

a. The personnel of the U. S. Army Materiel Command should review current and especially future end items design and manufacture for possible fabrication by the powder metallurgy process where applicable.

b. Where more information and knowledge of the powder metallurgy process is required for obtaining real savings or unusual mechanical properties, the U. S. Army Materiel Command should conduct studies to exploit the tangible benefits.

c. Development resulting from U. S. Army contracts utilizing the powder metallurgy process should be widely disseminated so that maximum utilization of these developments (both favorable and unfavorable) can be achieved.

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