Title: MULTI-FUNCTION SPLIT POWDER METAL DIE

Abstract: A tool press has at least one split die (30) which is radially movable relative upper and lower die (10, 20) which are axially movable relative each other and may carry any number of associated upper or lower die punches (50, 40) and/or core rods. The split die (30) has at least one die segment which moves radially between an inner position to form radially inwardly extending recesses, bores or grooves in the part during compression and an outer, expanded position which facilitates removal of a compacted part from the press. The upper and lower die and their associated punches and core rods may form complex profiles, such as for gear teeth, and splines on the surfaces of the part on either axial side of the split die segments, and particularly on axial end surfaces of the part, on inner surfaces of bores of the part about core rods and on axially directed surfaces of bosses formed about annular circumferential grooves in the radially outwardly directed surfaces of the parts.
For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.
MULTI-FUNCTION SPLIT POWDER METAL DIE

Scope of the Invention

This invention relates to split dies for producing compacted parts out of powder material and, more particularly, to a device to form parts out of powdered material and, particularly, spool-shaped parts.

Background of the Invention

It is known to produce parts by compacting powder material to produce a compacted part and then sintering the compacted part. Subsequently, the sintered part may be machined, calibrated, heat treated and/or subjected to such other operations and/or treatment as the part specifications may require.

Devices to compact parts out of powdered material for sintering are well known to those persons skilled in the art and include the devices taught by U.S. Patent 5,698,149 to Hinzmann et al issued December 16, 1997.

The present inventor has appreciated that previously known devices for compacting parts to be sintered by compressing powdered material are not effective to form many parts which have grooves extending inwardly as, for example, are found in parts of spool-like shape. Parts of spool-like shapes typically have a ring-like member at each end connected by an axially extending member of reduced radius. Previously known devices to compact parts to be sintered do not provide for forming such spool-like parts by compression axially relative the spool-like parts.

The present inventor has appreciated that many parts and particularly spool-like parts, such as a synchronizing sleeve used in manual transmissions, carriers used in automatic transmissions, connecting rods and phased sprockets used to transfer power from the engine to front wheel drive automatic transmissions, cannot be advantageously manufactured by existing methods and processes for compacting powdered materials. Presses to compact parts from
powdered metals are commercially available and able to accommodate various tool systems including those disclosed in this invention.

Summary of the Invention

To partially overcome these disadvantages of previously known devices, the present invention provides a device to compact a part out of powdered metal which device has upper and lower dies which move relative to each other along an axis and an intermediate, preferably split die disposed between the upper and lower dies and comprising one but preferably two or more annular segments movable towards and away from the axis, preferably radially relative the axis. The present invention also provides for products such as a spool-like product manufactured by compacting powdered material and particularly synchronizing sleeves for manual transmissions, carriers used in automatic transmissions, connecting rods and phased sprockets used to transfer power from the engine to front wheel drive automatic transmissions.

An object of the present invention is to provide a device and method to produce parts compacted from powdered metal.

Another object is to provide a device and method to produce a spool-like product by compacting powdered metal utilizing a tool which includes a plurality of dies in which at least some of the dies are movable axially relative to each other and at least one other of the dies are movable radially relative each other.

Another object is to provide a method of manufacture of a synchronized sleeve, carriers used in automatic transmissions, connecting rods and phased sprockets used to transfer power from the engine to front wheel drive automatic transmissions from powdered metal by compacting, sintering and other operations and/or treatments as required for the part.

Another object is to provide a device and method for producing spool-like parts and, particularly, synchronizing sleeves for motor vehicle transmissions,
carriers used in automatic transmissions, connecting rods and phased sprockets used to transfer power from the engine to front wheel drive automatic transmissions, more simply and more cheaply.

Accordingly, in one aspect, the present invention provides a tool set to compact a part out of powder material, comprising:

a lower die,

an upper die,

a split die,

the lower die and upper die movable relative each other along an axis,

the split die disposed axially between the upper die and the lower die axially movable relative one of the upper die and lower die,

the split die comprising at least two annular segments disposed about the axis, each segment movable radially of the axis relative the lower die between a closed inner position in which the segments form a closed annular ring about the axis and an open expanded position in which each segment is located radially outwardly from the axis relative its inner position,

the lower die and upper die axially movable between an open position permitting insertion of powder material into the lower die and a closed position in which the lower die and upper die sandwich the split die there between with the split die segments in the inner position,

a locking mechanism to releasably lock the split die segments in the inner position,

at least one lower punch associated with the lower die for relative movement in the lower die along the axis,

at least one upper punch associated with the upper die for relative movement in the upper die along the axis,

with the lower die and upper die sandwiching the split die therebetween, with the split die segments in the inner position, and with the upper and lower punch engaged in the upper and lower die, a chamber is defined within the upper die, lower die and split die segments closed at upper and lower axial
ends thereof by the upper and lower punch,

at least one split die segment having a key portion which extends radially in to the cavity relative the upper and lower die such that an upper portion of the cavity is axially above the key portion and a lower portion of the cavity is axially below the key portion.

In another aspect, the present invention provides a tool set to compact a part out of powder material, comprising:

a lower die,

an upper die,

an intermediate key die,

the lower die and upper die movable relative each other along an axis,

the key die disposed axially between the upper die and the lower die axially movable relative one of the upper die and lower die,

the key die comprising at least one segment movable normal of the axis relative the lower die between an inner position and outer position in which the segment is located outwardsly from the axis relative its inner position,

the lower die and upper die axially movable between an open position permitting insertion of powder material into the lower die and a closed position in which the lower die and upper die sandwich the key die there between with the segment in the inner position,

at least one lower punch associated with the lower die for relative movement in the lower die along the axis,

at least one upper punch associated with the upper die for relative movement in the upper die along the axis,

with the lower die and upper die sandwiching the key die therebetween with the key die segment in the inner position and with the upper and lower punch engaged in the upper and lower die, a chamber is formed defined bordered by the upper die, lower die and key die segment and closed at upper and lower axial ends thereof by the upper and lower punch,

the key die segment comprising a key portion which extends radially
into the cavity relative the upper and lower die such that an imaginary line drawn parallel the axis through the key portion passes through both an upper portion of the cavity axially above the key portion and a lower portion of the cavity axially below the key portion.

In another aspect the present invention provides a method of forming a connecting rod for an internal combustion engine,

the connecting rod having an elongate body with a first bore extending transversely through a first end of the body and a second bore extending through the other second end of the body parallel the first bore,

the connecting rod splittable at its second end in a split plane extending transversely of a longitudinal of the body and axially bisecting the second bore,

the method comprising forming a compacted part by compacting the connecting rod from metal powder followed by sintering the compacted part,

the compacting of the metal powder carried out compacting the metal powder in a tool press between upper and lower dies movable relative each other in a direction parallel the axis of the first bore, the tool press including a split die adapted to be sandwiched between the upper and lower dies and having at least one die segment movable radially relative the axis of the first bore,

the split die segment forming radially outwardly directed surfaces of the connecting rod on one side of the split plane.

In another aspect the present invention provides a method of forming a part selected from a synchronizing sleeve for automotive transmissions, and a phased sprocket for front wheel drive automatic automotive transmissions,

wherein the part has a spool shape about a central part axis, an external surface directed radially outwardly from the part axis, a groove extending radially into the external surface of the part, a central bore through the part about the part axis, and, an internal surface directed radially inwardly toward the part axis within the central bore, the internal surface being splined,

the method comprising forming a compacted part by compacting metal powder in a tool press followed by sintering the compacted part,
the compacting of the metal powder carried out compacting the metal powder between upper and lower dies movable relative one another in a direction parallel the part axis,

the tool press powder including a split die adapted to be sandwiched between the upper and lower dies and having a plurality of die segments movable radially relative the part axis between an inner, engaged position in which the die segments form the groove during compaction and an outer, expanded position permitting removal of the compacted part.

The present invention teaches a novel split die which is adapted to manufacture parts out of metal powder which have undercut portions. The invention also teaches specific methods for making parts by compacting and sintering and specific parts which can be made with the split die and method of the invention.

A tool press in accordance with the invention preferably has at least one split die which is radially movable relative upper and lower die. The upper and lower dies are axially movable relative each other and may carry any number of associated upper or lower die punches and/or core rods. The split die has at least one die segment which moves radially between an inner position to form radially inwardly extending recesses, bores or grooves in a part to be formed during compression and an outer, expanded position which facilitates removal of a compacted part from the tool press. The upper and lower dies and their associated punches and core rods may form complex profiles, such as for gear teeth, and splines on the surfaces of the part on either axial side of the split die segments, and particularly on axial end surfaces of the part, on inner surfaces of bores of the part about core rods and on axially directed surfaces of bosses formed about annular circumferential grooves in radially outwardly directed surfaces of the parts. By forming such complex profiles with the dies in compacting, later machining steps are reduced or avoided. Where the part is spool shaped with a central bore, after sintering the part may further be formed and its surface hardened by roll forming also known as ring rolling.
Brief Description of the Drawings

Further aspects and advantages of the present invention will become apparent from the following description taken together with the accompanying drawings in which:

Figure 1 is a cross-sectional side view of a first embodiment of a tool system or press for making die formed parts in accordance with the present invention in a fully open position after filling;

Figures 2, 3, 4 and 5 are, respectively cross-sectional side views of the first embodiment of the present invention shown in Figure 1 in a transfer position (Figure 2), a press ready position (Figure 3), a fully compacted position (Figure 4) and an ejection position (Figure 5);

Figure 6 is a top view of the press of Figure 1 along line 6-6' in Figure 1;

Figure 7 is a cross-sectional side view of a second embodiment of a press for making die forming parts in accordance with the present invention in a fully open position after filling;

Figures 8 and 9 are, respectively cross-sectional side views of the second embodiment of the press shown in Figure 7 in a transfer position (Figure 8) and in a press ready position (Figure 9);

Figure 10 is a cross-sectional side view of a third embodiment of a press for making die forming parts in accordance with the present invention in a fully open position after filling;

Figures 11 and 12, respectively, are cross-sectional side views of the third embodiment of the press shown in Figure 10 in a transfer position (Figure 11) and a press ready position (Figure 12);

Figure 13 is a cross-sectional side view of a fourth embodiment of a press for making die forming parts in accordance with the present invention in a fully open position after filling;

Figures 14 and 15, respectively are cross-sectional side views of the
fourth embodiment of the press shown in Figure 13 in a second filling position (Figure 14) and in a press ready position (Figure 15);

Figure 16 is a schematic cross-sectional view along a diameter of a synchronizer sleeve for a manual transmission as suitable for manufacture with the apparatus and method of the present invention;

Figure 17 is a schematic cross-sectional view of a roll forming apparatus as shown and used to roll the synchronizer sleeve shown in Figure 16;

Figure 18 is a schematic pictorial view showing two portions of a carrier for an automatic automotive transmission;

Figure 19 is a schematic pictorial view of a one-piece carrier having the features of the carrier shown in the exploded view in Figure 18;

Figure 20 is a pictorial view of a typical engine connecting rod used in an internal combustion engine;

Figure 21 is a schematic view of a split die tooling arrangement suitable for manufacture of the connecting rod of Figure 20 in accordance with the method and apparatus of the present invention;

Figure 22 is a cross-sectional end view of a phased sprocket used to connect the driving device to a driven device by means of two chains;

Figure 23 is a schematic pictorial view of one spool-like member;

Figures 24 and 25 are schematic pictorial views of second and third spool-like members of a configuration preferred for manufacture with a split die press in accordance with the present invention;

Figure 26 is a schematic pictorial view of a part of a configuration for manufacture with a die press in accordance with the present invention; and

Figure 27 is a schematic cross-sectional elevation view of a press carrying a tool set corresponding to that shown in Figure 1.

Detailed Description of the Drawings

Throughout the disclosure of the different embodiments, similar reference numerals are used to refer to similar elements.
Reference is made first to Figures 1 to 6 which show a first embodiment of a press for making die formed parts from metal powder. The press of Figures 1 to 6 includes disposed about a die axis 100, an upper die 10, a lower die 20, a split die 30, a lower punch 40, an upper punch 50 and a die table or press bench 60. As seen in Figure 6, the split die 30 is formed by two annular segments 31 and 32 which are movable radially of the axis 100 between an open position as shown in Figures 1, 5 and 6 and a closed position shown in Figures 2, 3 and 4. In the closed position, the annular segments have their surfaces 33 and 34 engage each other and the segments form a circular annular ring about the axis 100. The split die segments 31 and 32 are radially slidable relative the other elements and particularly relative the lower die 20.

The upper die 10 and upper punch 50 are shown as associated with each movable along the axis 100 relative to each other and to the other elements of the press.

Similarly, the lower die 20 and lower punch 40 are shown as associated with each movable along the axis 100 relative to each other and to the other elements of the press.

Figure 1 shows a fully open position of the press in which the press elements are positioned as is desired to permit the filling of a fill cavity 70 within the lower die 20 with metal powder. As shown in Figure 1, the upper die 10 and associated upper punch 50 are axially spaced from the split die 30 and lower die 20 sufficiently to permit metal powder to be inserted into and to fill the fill cavity 70 as shown, for example, to the upper surface of the lower die 20. The lower punch 40 is shown as drawn downwardly relative the lower die 20 to an extent sufficient to define the fill cavity 70 within the lower die 20 of desired volume. The split die 30 has its segments 31 and 32 in an open position spaced radially outwardly from axis 100 sufficient to preferably fully expose a circular opening in the lower die 20 which accommodates the lower punch 40.

After filling, fill cavity 70 with metal powder, the press elements are then moved to the transfer position shown in Figure 2. In this regard, the split die
segments 31 and 32 are moved radially together and the upper die 10 is moved downwardly on top of the split die 30.

The lower surface of the upper die 10 is shown as carrying a downwardly extending annular boss 102 to be received in a correspondingly sized annular groove 104 in the upper surface of the segments 31 and 32. The boss 102 serves to lock the segments 31 and 32 into an annular ring secured against radial movement. The upper punch 50 is axially located within the upper die 10 at a position as shown in Figure 2 so as to define above the fill cavity 70 a transfer chamber 80 of desired volume. The split die 30 extends radially into the transfer chamber 80 beyond the radially inner extent of the lower die 20 and the upper die 10.

From the position of Figure 2, the elements are moved to the press ready position of Figure 3 as, for example, by relative movement of the lower punch member 40 upwardly to the position shown in Figure 3. As seen in Figure 3, there remains a press ready chamber 90, which is filled with metal powder. The volume of press ready chamber 90 is preferably equal to the volume of the fill cavity 70. Relative movement of the lower punch 40 from the position of Figure 2 to the position of Figure 3 transfers metal powder from the fill cavity 70 into the transfer chamber 80 past the split die 30 so as to totally fill the transfer chamber 80. As seen in Figure 3, the split die segments 31 and 32 provide a key portion 36, which extends radially inwardly toward the axis beyond the adjacent sidewalls of the upper and lower die. The key portion 36 extends radially into chamber 90 relative the upper and lower die such that an upper portion of the chamber 90 is axially above the key portion 36 and a lower portion of the chamber 90 is axially below the key portion 36.

From the position of Figure 3, the upper punch 50 and lower punch 40 are moved axially towards each other so as to compress the powder in chamber 90 into a pressed part 110 having the shape and size as shown in Figure 4. The upper punch 50 and lower punch 40 are both moved axially toward each other and relative the split die 30 such that compression of metal powder axially onto axially
directed surfaces of the split die 30 occurs both above and below the split die 30. The key portion 36 of the split die 30 has an axially upwardly directed upper shoulder 33 and an axially downwardly directed lower shoulder 34 with radially directed surfaces 35 therebetween.

Powder material radially inwardly of the key portion 36 is compressed by axial compression from the directions, i.e., under forces applied by both punches 40 and 50. Powder material radially outward of key portion 36 is either above or below the key portion 36 and is compressed into the key portion by axial compression by one of the two punches 40 and 50. Powder material axially above key portion 36 is compressed between key portion upper shoulder 33 and upper punch 50. Powder material axially below key portion 36 is compressed between key portion lower shoulder 34 and lower punch 40.

Subsequently, as shown in Figure 5, the press is opened and with the upper die 10 and upper punch 50 moved upwardly to their position in Figure 1, the split die 30 is split with its segments 31 and 32 moved radially to their open positions in Figure 1. The lower die 20 is moved downwardly relative the lower punch 40 to present the pressed part 110 to the top of lower die 20 and press bench 60 ready for removal. Subsequently, the lower die 20 may be relatively moved upwardly to the position of Figure 1 to place the press in the fully open position of Figure 1 and the cycle is completed.

A tool set for making parts such as illustrated in Figures 1 to 5 may be mounted in a press 200, as schematically shown in Figure 27 as is well known in the powdered metal industry. The press 200 includes an upper ram 202 and a lower ram 204 both of which are movable relative the press 200 along axis 100. The upper ram 202 carries the upper die 10 and upper punch 50. The upper punch 50 is fixed to upper ram 202. The upper die 10 is coupled to the upper ram 202 for relative axial movement by hydraulic cylinder 206.

The lower punch 40 is fixed to a press table 208 forming a fixed part of the press 200. The die table 60 is mounted on the lower ram 204 by supports 210 extending through the press table 208. The die table 60 has lower die 20 fixed
thereto. Two hydraulic cylinders 212 and 214 are carried by the die table 60 and serve to move the split die segments 31 and 32 radially, that is horizontally.

Reference is now made to Figures 7 to 9 showing a press in accordance with a second embodiment of the invention and adapted to function in a manner similar to that of Figures 1 to 6 with the exception that in Figures 7 to 9, the lower punch 40 of the first embodiment has been replaced by the more complex lower punches 41 and 42 and core rod 43 and the upper punch 50 of the first embodiment has been replaced by the more complex upper punches 51 and 52. The additional punches also have the function of defining the height of the powder column at the press ready position in the press ready stage in order to equalize density for the various sections of the pressed part. Figures 1 to 6 illustrate a simple tool system which may be useful for some powder metal parts. However, more likely, the system used is that illustrated by Figures 7 to 9.

As shown, Figure 7 is a fully open filled position with a fill cavity 70 defined inside lower die 20, however, annularly about the core rod 43 and above appropriately positioned lower inner punch 42 and outer lower punch 41. The core rod 43 is shown with its top positioned appropriately at the height of the upper surfaces of the lower die 20 to facilitate filling to the upper surface of the lower die 20. The volume of the fill cavity 70 is preferably predetermined and set by the relative axial location of punches 42 and 41.

Figure 8 shows a transfer position with the segments 31 and 32 in the closed position and held locked in position by upper die 10. The upper inner annular punch 52 and the upper outer annular punch 51 are located to define a closed transfer chamber 80 of desired volume. The core rod 43 fits into the inside diameter of the upper punch 52 to effectively close the upper end of the transfer chamber 80.

From the transfer chamber 80 of Figure 8, the lower punches 41 and 42 are moved upwardly, the same could be accomplished by moving the rest of the tool system downward to the position of Figure 9 to transfer powder from fill cavity 70 into transfer chamber 80 and provide a resultant powder filled press
ready chamber 90. Subsequently, relative axial movement of the upper punches 51 and 52 and lower punches 41 and 42 result in forming a compacted part in an analogous manner as shown in Figure 4 for later ejection or removal and subsequent return of the press to the fully open position of Figure 7.

Reference is made to Figures 10 to 12 which show a third embodiment of a press in accordance with the present invention. Figure 10 shows a split die having two segments 31 and 32 similar to that of the first embodiment in being able to assume an open radially split apart position as shown in Figure 10 and a closed position as shown in Figures 11 and 12. In Figure 10, the segments 31 and 32 are radially slidable upon the upper surfaces of table 60 and of the lower outer die 21. In Figure 10, the upper die 10 and its upper punch 50 are axially spaced away from the lower die to permit powder to be placed into the fill cavity 70. The fill cavity 70 is formed by lower inner die 20 having its upper surface located at the upper surface of the lower outer die 21 as shown for convenience and with the position of lower punch 40 defining the volume of the fill cavity 70.

From the fill position of Figure 10, the split die segments 31 and 32 are moved radially inwardly to a closed position forming a closed annular ring. The upper die 10 and its associated upper punch 50 are moved axially to sandwich the split die between the upper die 10 and the lower die 20. The upper punch 50 is positioned to define a suitably sized transfer chamber 80. Die 10 has a boss 102 which fits into a correspondingly sized 104 in the die segments 31 and 32 in order to precisely locate them directly over cavity 70. Preferably, as shown, the lower die 20, split die 30 and upper die 10 are positioned axially to be within the outer lower die 21 such that the outer lower die 21 holds the split die segments 31 and 32 in the closed position against radial movement and die 10 and 20 hold the split die segments 31 and 32 against axial movement.

From the transfer position of Figure 11, the lower punch 40 is moved upwardly, the same could be accomplished by moving the rest of the tool system downwardly, to transfer powder from the cavity 70 into the chamber 80 and to fill the resultant press ready chamber 90 with powder as seen in the press ready
position of Figure 12 from which compression with both the punches 40 and 50 will produce the desired part.

Reference is made to Figures 13 to 15 which show a fourth embodiment of a punch which is similar to that of Figures 10 to 12, however utilizes a modified split die 30 to permit two separate filling steps.

Figure 13 shows an open primary filling position with a primary fill cavity 71 defined within the lower die 20 above the lower punch 40 to receive powder.

Figure 14 shows an open secondary filling position in which a secondary fill chamber 72 is defined above the primary fill cavity 71 radially inside the split die 30. To move from the position of Figure 13 to the position of Figure 14, the split die segments 31 and 32 have been moved radially to be located axially above inner lower die 20. Subsequent relative downward movement of the inner lower die 20 and its punch 40 permit the split die segments 31 and 32 to be received within the outer lower die 21. In the secondary fill position as shown in Figure 14, a second allotment of powder is added to fill the secondary fill cavity 72.

From the secondary fill position of Figure 14, the upper die 10 and upper punch 50 are moved downwardly onto the top of the split die segments 31 and 32 and thus effectively form the press ready chamber of Figure 15 which comprises merely the first fill cavity 71 and the second fill cavity 72. From the press ready position of Figure 15, a part may be compressed by axial movement of the punches 40 and 50.

A variation of the third and fourth embodiments would have one more upper punch and one more lower punch depending on the configuration of the part to be compacted and the height of the powdered metal column required in filling and transferring in order to achieve uniform density in the various sections of the part.

The split die 30 is illustrated as formed from two semi-circular segments 31 and 32. The split die may be formed for more than two segments, for
example, three or four or more segments which can be split apart as, for example, by movement relative to each other and movement preferably radially relative the axis 100.

Additionally, one of the split die segments 31 and 32 could serve to support a rod-like member which would extend radially of the axis 100 from one split die segment 31 to the other split die segment as, for example, and be supported at each of its ends in holes in the segments. Such a rod-like member could permit for resultant parts to have an opening extending therethrough perpendicular to the axis 100 and with the radial opening of the segments 31 and 32 providing a means for removably securing the rod member. The rod-like members could also be arranged to permit withdrawal independently after compaction before the opening of the split die segments 31 and 32. For example, by being separately movable radially independent of the split die segments. Similarly, one of the segments 31 and 32 could be constructed in a such way that one of them extends radially into the cavity across the cavity as a rod-like member which fits into a corresponding opening in the other of the segments 31 and 32. With such a rod-like projection of one of the segments 31 and 32 extending transverse to the axis 100, the rod-like extension would permit for forming of openings perpendicular to the axis 100.

The first and second embodiments show the split die segments held in a locked position by keyed engagement of a boss 102 on the upper die 10 within a groove 104 on the split die segments. Many other arrangements may be utilized to lock the split die segments together. For example, the split die segments could be contained throughout its thickness all around its circumference by the outer part of the top die which in this area is longer than the rest of the top die by the thickness of the split die or they could be mechanically secured to each other. The split die segments could be releasably pinned to each other or to either of the upper or lower dies 10 or 20 or to the table 60. The upper and lower dies could have radially inwardly directed engagement surface to engage radially outwardly directed engagement surfaces of the dies 31 or 32 and hold the segments in a
locked position. The engagement surfaces may be beveled to urge the split die segments radially together on sandwiching of the split die segments between the upper and lower dies.

Reference is made to Figure 16 which shows a simplified view of a typical synchronization sleeve 120 for a manual transmission for an automobile. The sleeve 120 has a generally spool-like shape. The sleeve 120 is annular about axis 100 and has radially outwardly directed surface 122 with an annular groove 124 extending between two circumferential bosses 126 and 128. The sleeve 120 has a radially inwardly directed surface 130 with axially extending teeth-like splines 132. One axially directed end of the sleeve 120 has axially directed spline points 134 circumferentially about the sleeve and the other axially directed end of the sleeve 120 has axially directed spline points 136 circumferentially about the sleeve. The sleeve 120 can be made with the apparatus and methods of the present invention utilizing, for example, a press with a tool system somewhat along the lines of that shown in the second embodiment of Figures 7 to 11. In this regard, the annular groove 124 can be made by the split die segments 31 and 32. The splines 132 in the inwardly directed surface 130 can be made by the core rod 43. The spline points 134 at one end can be made by the punch 41 and the spline points 136 at the other end can be made by punch 51. The axial outer surface of one of the bosses 126 can be made by punch 41 and the axial outer surface of the boss 128 can be made by punch 52.

After forming the sleeve 120, the sleeve is sintered. After sintering, the sintered part may preferably be subject to roll forming also known as ring rolling. Reference is made to Figure 17 showing a schematic cross-sectional side view of a roll forming apparatus having a first die roller 140 and a second die roller 142 each rotatable parallel axis 144 and 146, respectively. The first and second rollers 140 and 142 preferably can be moved towards and away from each other normal their axis. With the rollers spaced apart, the sintered sleeve 120 may be axially slid over one of the rollers, preferably, over the second roller 142. The rollers are then moved towards each other to catch the sleeve 120 in the cavity.
formed between both rollers 140 and 142 and closed at either axial ends by shoulders 121. The rollers 140 and 142 have outer surfaces of shapes and sizes desired for the inner and outer surfaces of the sleeve 120. While rotating the rollers 140 and 142, pressure is applied to move the rollers slightly closer together and further compress the sleeve 120. The sleeve 120 initially placed between the rollers becomes slightly reduced in volume by compression and rotation of the rollers.

An advantage of such roll forming is that it increases the density of the sintered metal at the surfaces thereof while urging the sleeve 120 into desired form and dimensions. The densification of the surfaces, even if only to a few thousandths of an inch, makes the sleeve stronger and more resistance to wear at locations where wear may be expected. Densification is possible because compacted powder metal parts even after sintering are not fully dense, after rolling, the designated areas are practically fully dense at the surface and gradually less dense to no effect at a depth of 15 to 40 thousands of an inch.

Compacted and sintered powder metal parts have low ductility that normally is indicated by elongation less than two percent. Form rolling has a disadvantage that it requires relatively significant deformation to transfer a rough powder metal blank which typically causes cracks in the blank and, accordingly, form rolling has not been used to manufacture powder metal sleeves. The present invention in providing for initial compaction of the synchronized sleeve in the split die press permits the sleeve to initially be formed having dimensions close to the desired final dimensions of the sleeve. Thus, the initial compaction can form the annular groove 120 and the internal splines 132 and spline points 134 and 136 close to the final dimensions thus permitting the subsequent use of form rolling to make minor adjustments to the shape and dimension without cracking the sleeve and, at the same time, densifying the surfaces and, particularly, the spline points 134 and 136.

The present invention in combining powder metal die compaction with roll forming provides a manufacturing method for forming products and
particularly the sleeves such as the illustrated synchronization sleeve that is less expensive than other methods currently used. As is to be appreciated, some final machining may be necessary depending upon the configuration and tolerances of the desired sleeve.

Reference is made to Figures 18 and 19 which show a carrier for an automatic automobile transmission. Figure 18 shows an exploded view of a top plate 150 and bottom plate 151 of a carrier for an automatic automobile transmission. The top plate 150 and bottom plate 151 are typically manufactured separately then sinter bonded together to form a final unitary product 153 as shown in Figure 19. In such a two-step manufacture, it is typically only after bonding the two plates together that the four holes 154 are drilled. The top plate 150 is a disc about axis 100 and has a central bore 155 with internal splines and four axially extending holes 154. The lower plate is also disposed about axis 100 and has a central bore 156. The bottom plate 151 has four upstanding legs 157 formed between two radially extending rectangular passageways 158 and 159 disposed at right angles to each other and extending entirely through the disc 151 above a base. The present invention provides an apparatus and method for manufacturing the carrier shown in Figure 19 as a unitary part by compaction of powder metal. The rectangular passageways which extend at right angles to each other can be made by the use of a split die having four separate die portions each of which extends radially into the die cavity from separate quadrants about the die. Preferably, a core rod such as 43 may be utilized to form the central bore 156 in the lower plate and the spline bore 155 in the upper plate. The segments of the split die may extend inwardly, for example, to contact on the core rod such as 43.

Reference is made to Figure 20 which shows a schematic pictorial view of a typical connecting rod 160 for an internal combustion engine. The connecting rod 160 has an elongate body 162 with two holes 164 and 166 at each end. The holes 164 and 166 extend along parallel axis. The smaller hole 164 is adapted to be connected to an engine piston and the larger hole 166 is adapted to be connected to an engine crank shaft. The connecting rod 160 is normally
manufactured as one part and subsequently separated along a split line 172 across hole 166 into two parts 168 and 170 such that the two parts may be bolted together onto a crank shaft using bolts which extend through two holes 176 which extend substantially perpendicular to the axis of the holes 164 and 166.

Figure 21 schematically shows one version of a split die in accordance with the present invention adapted to form the connecting rod shown in Figure 20 by compression from powder metal. Figure 21 schematically illustrates two split dies 30 and 31 adapted for use in a split die to form the connecting rod 160. Figure 21 also schematically shows two core rods indicated as 46 and 47 which are adapted to form the holes 164 and 166 and would be moved upwardly and downwardly along the axis of the press so as to be received in an appropriate location within the two split dies 31 and 32 as shown as well as within other dies and upper punches necessary to form the complete set of tooling to form the connecting rod 160. The split die 31 and split die 32 are adapted to move radially of the core rods 47 and 46 to engage each other and form a cavity having an outer profile of that of the connecting rod 160. The split die 31 is shown as carrying two rod-like insert members 176 which are adapted to be received in two corresponding bores 178 in the split die 32 and, thus, form the two connecting holes 176 in the connecting rod. It is to be appreciated that in use of the split dies 31 and 32 such as shown in Figure 21 that complementary upper and lower dies having a similar profile and complementary punches will need to be utilized.

Figure 21 shows two rectangular separating sheets 184. Each sheet has a hole therethrough such that the sheet can be slid axially onto the two rods 176 on the die 30. The separating sheets 134 extend from the outer edge of the split die 30 inwardly to an inner point where they will engage on the outer cylindrical surface of the punch 47. However, it is not necessary that the sheets 184 extend fully across the cross-section of the connecting rod since their purpose is merely to provide a weakened line about which the connecting rod may be split. When the split die is closed about the punch 37, the separating sheets 184 form a split line along which the connected rod 160 may be later split into its two portions.
Each separating sheet 184 preferably is of a material which is burnt off in sintering yet in burning off prevents bonding of the two portions together or at least bonding in a manner which provides for easy separation as by fracture of the two portions apart at the split line. The separating sheets alternatively could be non-consumable and could be reused after making each part.

Reference is now made to Figure 22 which schematically illustrates a cross-sectional phased sprocket 190 for the transfer of power by means of chains from a source of power to a device that uses the power. The phased sprocket is annular about its axis 100 and has an inner bore 191 with splines 192. The phased sprocket has two sets of similar gear teeth 195 and 196 on its outside cylindrical surface with the gear teeth 195 out of phase from gear teeth 196. The bosses and their gear teeth are separated by an annular circumferential groove 197 which prevents a chain received on each gear set from interfering with the chain on the other gear set.

It is to be appreciated that a phased sprocket as shown in Figure 22 can be made in accordance with the present invention with the groove between the gear sets being made by the split die segments. The separate punches at either axial end can be used to form the two gear sets. A core rod can be used to form the spline.

The part 110 shown in Figure 5 has a spool-like shape with enlarged axial end portions and a reduced center portion when considered in respect of radial dimensions measured from the axis. The press of the present invention is adapted for powder forming of such spool-like shaped parts by axial compression in a press with axially movable primary dies and a radially splittable split die. Such parts as may be advantageous for forming in accordance with the present invention have features which can not be formed merely by compression with dies which move merely along an axis. Parts of spool-like shape as shown in Figures 23 to 26 cannot be formed merely by moving the dies along the single axis. Rather, these parts can preferably be formed in accordance with the present invention as by use of a split die with the primary axis of the compression
preferably along the axis of the spool-like member.

Reference is made to Figure 26 which shows a part 118 advantageously made with a tool set in accordance with the present invention with a form of the tool shown in Figures 1 to 6 modified such that the key portion 36 of the split die 30 will merely form a blind key hole shown as 120 in Figure 26. The split die 30 of Figure 4 is shown to have a key portion 36 which extends radially inwardly beyond the upper and lower dies about the entire circumference, that is 360° about the axis 100. The split die 30 of Figure 4 may have its key portion 36 removed except in a small segment, for example, about 30° about the axis 100 to provide a reduced size key portion adapted merely to form the blind key hole 120 in Figure 26. It is to be appreciated that such a reduced size segment of the key portion could be provided on but a single segment as on merely the split die segment 31 and the other split die segment 32 could be eliminated, for example with its space occupied by the upper or lower dies 10 and 20.

The disclosure has shown the tool sets orientated with the axis 100 vertical and has used the terms upper and lower to describe relative locations and movements. It is to be appreciated that the axis could be disposed at other angular orientations including horizontal. The key portion 36 and dies have been shown to be uniform about their circumferences in Figures 1 to 6. It is to be appreciated that the profiles of these members can vary about their circumferences within the proviso that preferably at each point with the cavity 90 powder material is open to direct application of axially forces and therefore axially in line with one of the punches 40 or 50.

A typical part may be formed from metal powder by compression in a tool set as for example described with reference to Figures 1 to 6. After sintering, the part may be repressed in different tools as, for example, to improve density and/or reduce dimensional variation. Thereafter, further machining, polishing, grinding and the like may be carried out to provide the part with desired features, tolerances and the like.

Figure 24 shows a part with not only the circumferential groove or
keyway about its circumference but also an axially inwardly extending bore 124, and which therefore can not be produced by a two-part mold which opens by two merely axially or merely radially relative axis100.

Figure 25 shows a part with the circumferential keyway and an upper sprocket 125 such that it also cannot be produced by a two-part mold which opens merely axially or merely radially. Similarly, the part of Figure 23 cannot be made from a two-part mold.

The split die arrangement disclosed is specifically adapted to form spool-like parts, however, may be used to form many other shaped parts. While reference has been made to preferred embodiments many other modifications and variations may occur to those skilled in the art. For a definition of the invention reference is made to the claims.
WHAT I CLAIM:

1. A tool set to compact a part out of powder material, comprising:
   a lower die,
   an upper die,
   a split die,
   the lower die and upper die movable relative each other along an axis,
   the split die disposed axially between the upper die and the lower die
   axially movable relative one of the upper die and lower die,
   the split die comprising at least two annular segments disposed about the
   axis, each segment movable radially of the axis relative the lower die between a
   closed inner position in which the segments form a closed annular ring about the
   axis and an open expanded position in which each segment is located radially
   outwardly from the axis relative its inner position,
   the lower die and upper die axially movable between an open position
   permitting insertion of powder material into the lower die and a closed position in
   which the lower die and upper die sandwich the split die there between with the
   split die segments in the inner position,
   a locking mechanism to releasably lock the split die segments in the
   inner position,
   at least one lower punch associated with the lower die for relative
   movement in the lower die along the axis,
   at least one upper punch associated with the upper die for relative
   movement in the upper die along the axis,
   with the lower die and upper die sandwiching the split die therebetween
   with the split die segments in the inner position, and with the upper and lower
   punch engaged in the upper and lower die, a chamber is defined within the upper
die, lower die and split die segments closed at upper and lower axial ends thereof
by the upper and lower punch,
   at least one split die segment having a key portion which extends radially
in to the chamber relative the upper and lower die such that an upper portion of
the chamber is axially above the key portion and a lower portion of the chamber is axially below the key portion.

2. A tool set as claimed in claim 1 wherein every point within the chamber is in communication along a line parallel the axis with an axially directed surface of one of the upper punch or lower punch.

3. A tool set to compact a part out of powder material, comprising:

   a lower die,
   an upper die,
   an intermediate key die,
   the lower die and upper die movable relative each other along an axis,
   the key die disposed axially between the upper die and the lower die axially movable relative one of the upper die and lower die,
   the key die comprising at least one segment movable normal of the axis relative the lower die between an inner position and outer position in which the segment is located outwardly from the axis relative its inner position,
   the lower die and upper die axially movable between an open position permitting insertion of powder material into the lower die and a closed position in which the lower die and upper die sandwich the key die there between with the segment in the inner position,
   at least one lower punch associated with the lower die for relative movement in the lower die along the axis,
   at least one upper punch associated with the upper die for relative movement in the upper die along the axis,
   with the lower die and upper die sandwiching the key die therebetween with the key die segment in the inner position and with the upper and lower punch engaged in the upper and lower die, a chamber is formed defined bordered by the upper die, lower die and key die segment and closed at upper and lower axial ends thereof by the upper and lower punch,
the key die segment comprising a key portion which extends radially into
the chamber relative the upper and lower die such that an imaginary line drawn
parallel the axis through the key portion passes through both an upper portion of
the chamber axially above the key portion and a lower portion of the chamber
axially below the key portion.

4. A tool set as claimed in claim 3 wherein for every point within the
chamber an imaginary line within the chamber extends parallel the axis from each
point to an axially directed surface of one of either the lower punch or the upper
punch.

5. A tool set as claimed in claim 1 wherein

the lower punch defining a fill cavity within the lower die open for
receiving the powder material when the upper die and lower die are in the open
position and the split die segments are in the outer position with the fill cavity
comprising a lowermost portion of the chamber when the upper die and lower die
are in the closed position,

the split die segments movable from the expanded position to the inner
position when the upper die and lower die are in the open position,

the lower punch movable relative the split die segments when the upper
die and lower die are in the closed position and the split die segments are in the
inner position so as to transfer powder from the fill cavity into a portion of the
chamber above the fill cavity,

the upper punch and lower punch movable axially toward each other
when the upper die and lower are in the closed position to compact powder in the
chamber to produce a compacted part,

the upper die and lower die movable to the open position and the split
die segments movable to the expanded position for removal of the compacted part.

6. A tool set as claimed in claim 1 wherein one of the lower die and upper
die carrying radially inwardly directed engagement surfaces to engage radially
outwardly directed engagement surfaces on the split die segments to maintain the split die segments in the inner position,

axial movement of one of the lower die and the upper die relative the split die bringing the inwardly directed engagement surfaces into engagement with the outwardly directed engagement surfaces to block the split die segments in the inner position.

7. A tool set as claimed in claim 5 wherein the key portion extends from a first of the die segments to a second of the die segments.

8. A tool set as claimed in claim 7 wherein the first of the die segments is movable linearly in a first direction normal the axis, the key portion comprises an elongate rod member extending normal the axis and parallel the first direction.

9. A tool set as claimed in claim 8 wherein a first end of the rod member is carried by the first of the die segments and a second end of the rod member slidably engages within a complementary bore in the second of the die segments.

10. A tool set as claimed in claim 8 including a plate member supported on the rod member extending from the rod member in a plane transverse to a longitudinal of the rod member.

11. A method of compacting a part out of powder metal with a tool set comprising:
   a lower die,
   an upper die,
   a split die,
   the lower die and upper die movable relative each other along an axis,
   the split die disposed axially between the upper die and the lower die axially movable relative one of the upper die and lower die,
the split die comprising at least two annular segments disposed about the axis, each segment movable radially of the axis relative the lower die between a closed inner position in which the segments form a closed annular ring about the axis and an open expanded position in which each segment is located radially outwardly from the axis relative its inner position,

the lower die and upper die axially movable between an open position permitting insertion of powder material into the lower die and a closed position in which the lower die and upper die sandwich the split die there between with the split die segments in the inner position,

a locking mechanism to releasably lock the split die segments in the inner position,

at least one lower punch associated with the lower die for relative movement in the lower die along the axis,

at least one upper punch associated with the upper die for relative movement in the upper die along the axis,

with the lower die and upper die sandwiching the split die therebetween with the split die segments in the inner position, and with the upper and lower punch engaged in the upper and lower die, a chamber is defined within the upper die, lower die and split die segments closed at upper and lower axial ends thereof by the upper and lower punch,

at least one split die segment having a key portion which extends radially in to the chamber relative the upper and lower die such that an upper portion of the chamber is axially above the key portion and a lower portion of the chamber is axially below the key portion,

the lower punch defining a fill cavity within the lower die open for receiving the powder material when the upper die and lower die are in the open position and the split die segments are in the outer position with the fill cavity comprising a lowermost portion of the chamber when the upper die and lower die are in the closed position,

the split die segments movable from the expanded position to the inner position when the upper die and lower die are in the open position,
the lower punch movable relative the split die segments when the upper die and lower die are in the closed position and the split die segments are in the inner position so as to transfer powder from the fill cavity into a portion of the chamber above the fill cavity,

the upper punch and lower punch movable axially toward each other when the upper die and lower are in the closed position to compact powder in the chamber to produce a compacted part,

the upper die and lower die movable to the open position and the split die segments movable to the expanded position for removal of the compacted part,

the method including the steps of:
filling the fill cavity with metal powder with the upper die and lower die in the open position and the split die segments in the outer position,
moving the split die segments from the expanded position to the inner position,
moving the upper die and lower die to sandwich the split die therebetween and define said chamber,
moving the lower punch relative the split die segments to transfer powder from the fill cavity into the portion of the chamber above the fill cavity,
moving the upper punch and lower punch axially toward each other relative the split die segments to compact powder in the chamber to produce a compacted part.

12. A method as claimed in claim 11 wherein in the step of moving the lower punch relative the split die segments to transfer powder from the fill cavity into the portion of the chamber above the fill cavity, the chamber becomes completely filled with powder.

13. A method as claimed in claim 12 wherein while the lower punch is moved to transfer powder from the fill cavity into the portion of the chamber above the fill cavity, the upper punch is maintained at a fixed position relative the upper die so as to define the portion of the chamber above the fill cavity.
14. A method as claimed in claim 11 wherein the part has a spool shape about a central part axis and an external surface directed radially outwardly from the part axis, a groove extending radially into the external surface of the part, wherein the method is carried out with the part axis parallel the axis along which the lower die and upper die are movable and with the split die forming the groove.

15. A method as claimed in claim 14 wherein the part has an axially directed first end and an axially directed second end, the part axis extending from the first end to the second end, the first end including first gear teeth, the second end including second gear teeth, wherein the method is carried out with the lower punch forming the second gear teeth and the upper punch forming the first gear teeth.

16. A method as claimed in claim 15 wherein the tool set includes an axially extending core rod carried in an axially extending bore in one of the upper punch and lower punch and axially movable relative thereto, the part having a central bore therethrough about the part axis, the method carried out with the core rod forming the central bore of the part.

17. A method as claimed in claim 16 wherein the central bore of the part has axially extending splines formed in radially inwardly directed surfaces thereof formed by the core rod.

18. A method as claimed in claim 16 wherein the method including sintering the compacted part and after sintering, subjecting the sintered part to rolling to increase the density of interior surfaces of the part within the central bore and/or the exterior surface of the part at the same time forming the part in accordance to the rolling tools configuration as well as establishing dimensional tolerances according to the to the final part specifications.
19. A method as claimed in claim 14 wherein the groove comprises an annular circumferential groove between two annular, axially spaced circumferential bosses, each boss extending radially from the part axis farther than the groove, each of said bosses carrying gear teeth, wherein the method is carried out with the gear teeth formed by the upper and lower dies.

20. A method as claimed in claim 17 wherein the part is selected from a synchronizing sleeve for automotive transmissions and a phased sprocket for front wheel drive automatic automotive transmissions.

21. A method of forming a connecting rod for an internal combustion engine,

the connecting rod having an elongate body with a first bore extending transversely through a first end of the body and a second bore extending through the other second end of the body parallel the first bore,

the connecting rod splittable at its second end in a split plane extending transversely of a longitudinal of the body and axially bisecting the second bore,

the method comprising forming a compacted part by compacting the connecting rod from metal powder followed by sintering the compacted part,

the compacting of the metal powder carried out compacting the metal powder in a tool press between upper and lower dies movable relative each other in a direction parallel the axis of the first bore, the tool press including a split die adapted to be sandwiched between the upper and lower dies and having at least one die segment movable radially relative the axis of the first bore,

the split die segment forming radially outwardly directed surfaces of the connecting rod on one side of the split plane.

22. A method of forming a part selected from a synchronizing sleeve for automotive transmissions, and a phased sprocket for front wheel drive automatic automotive transmissions,
wherein the part has a spool shape about a central part axis, an external
surface directed radially outwardly from the part axis, a groove extending radially
into the external surface of the part, a central bore through the part about the part
axis, and, an internal surface directed radially inwardly toward the part axis within
the central bore, the internal surface being splined,

the method comprising forming a compacted part by compacting metal
powder in a tool press followed by sintering the compacted part,

the compacting of the metal powder carried out compacting the metal
powder between upper and lower dies movable relative one another in a direction
parallel the part axis,

the tool press including a split die adapted to be sandwiched between
the upper and lower dies and having a plurality of die segments movable radially
relative the part axis between an inner, engaged position in which the die
segments form the groove during compaction and an outer, expanded position
permitting removal of the compacted part.
FIG. 20

FIG. 22
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 B22F/03 B30B11/02 B21K1/30

According to International Patent Classification (IPC) or both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B22F B30B B21K F16D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
WPI Data, EPO-Internal, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>X</td>
<td>PATENT ABSTRACTS OF JAPAN</td>
<td>3-9</td>
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<tr>
<td>A</td>
<td>abstract</td>
<td>1,2, 11-14, 21,22</td>
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*A* document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search

1 August 2001

Date of mailing of the international search report

07/08/2001

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