US008210016B2

(12) **United States Patent**
Szuba et al.

(10) **Patent No.: US 8,210,016 B2**
(45) **Date of Patent: Jul. 3, 2012**

(54) **MULTI-STATION DIES FOR EXTRUDING TEETH**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 943 days.

(21) Appl. No.: **12/245,080**

(22) Filed: **Oct. 3, 2008**

(65) **Prior Publication Data**

US 2010/0083723 A1 Apr. 8, 2010

(51) **Int. Cl.**
B21C 23/04 (2006.01)
B21J 11/00 (2006.01)

(52) **U.S. Cl.** **72/264**; 72/405.01

(58) **Field of Classification Search** 72/264, 72/257, 405.01, 405.07, 419, 421, 426; 100/207; 414/226.04; 198/468.9, 580
See application file for complete search history.

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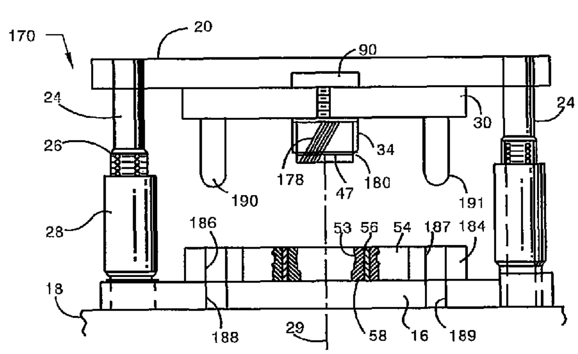
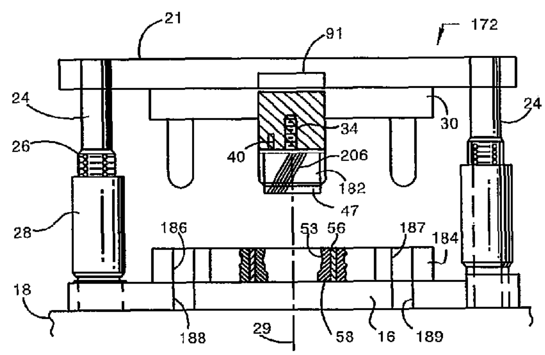
(57) **ABSTRACT**

A system for extruding teeth in a workpiece includes a first mandrel supported on a first press and including first die teeth that produce partially formed teeth on the workpiece as the first die teeth are extruded into the workpiece by the first press, a second mandrel supported on a second press and including second die teeth that produce fully formed teeth on the workpiece as the second die teeth are extruded into the workpiece by the second die station, and a transfer system for supporting and carrying the workpiece with the lower die assembly from the first press to the second press.

18 Claims, 4 Drawing Sheets





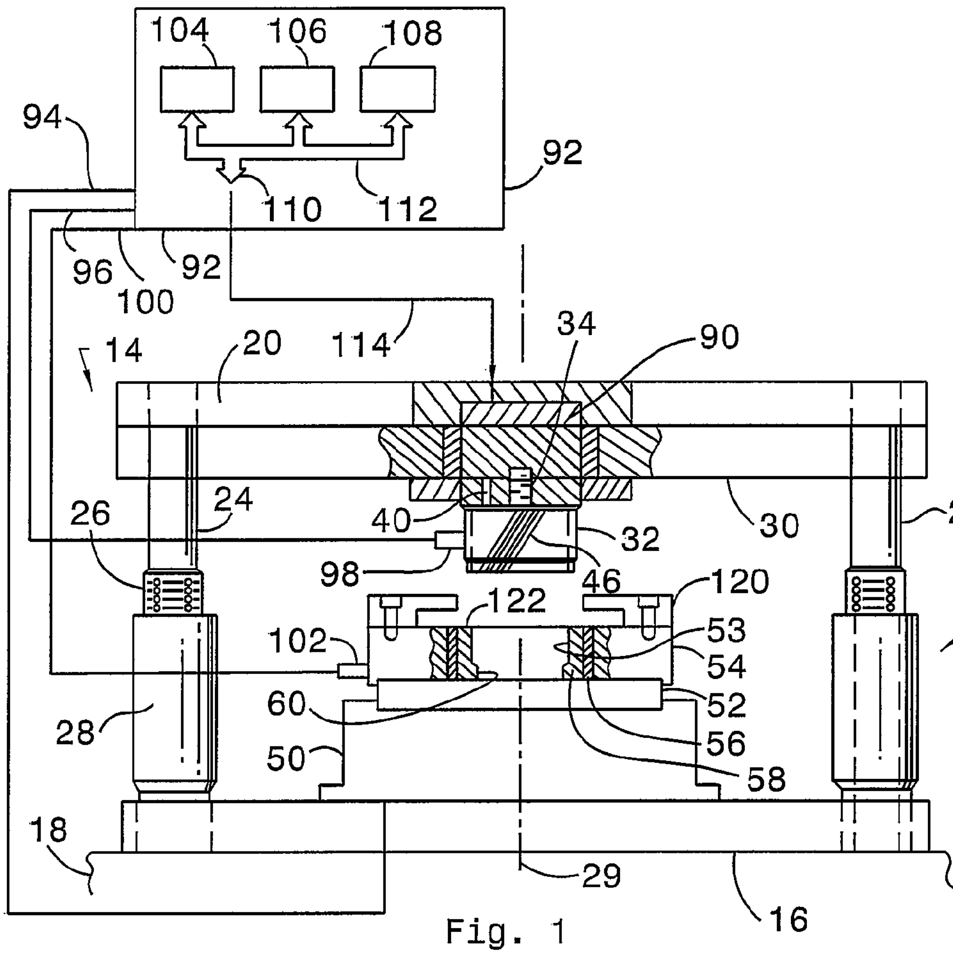

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Fig. 1

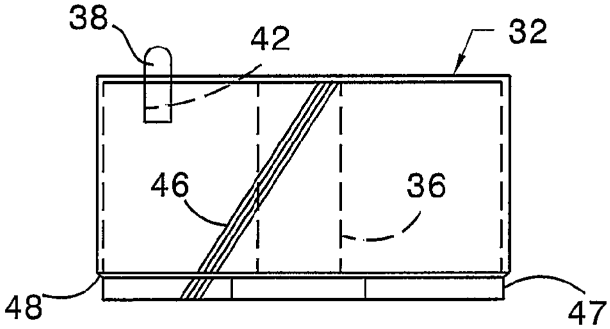
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Fig. 2

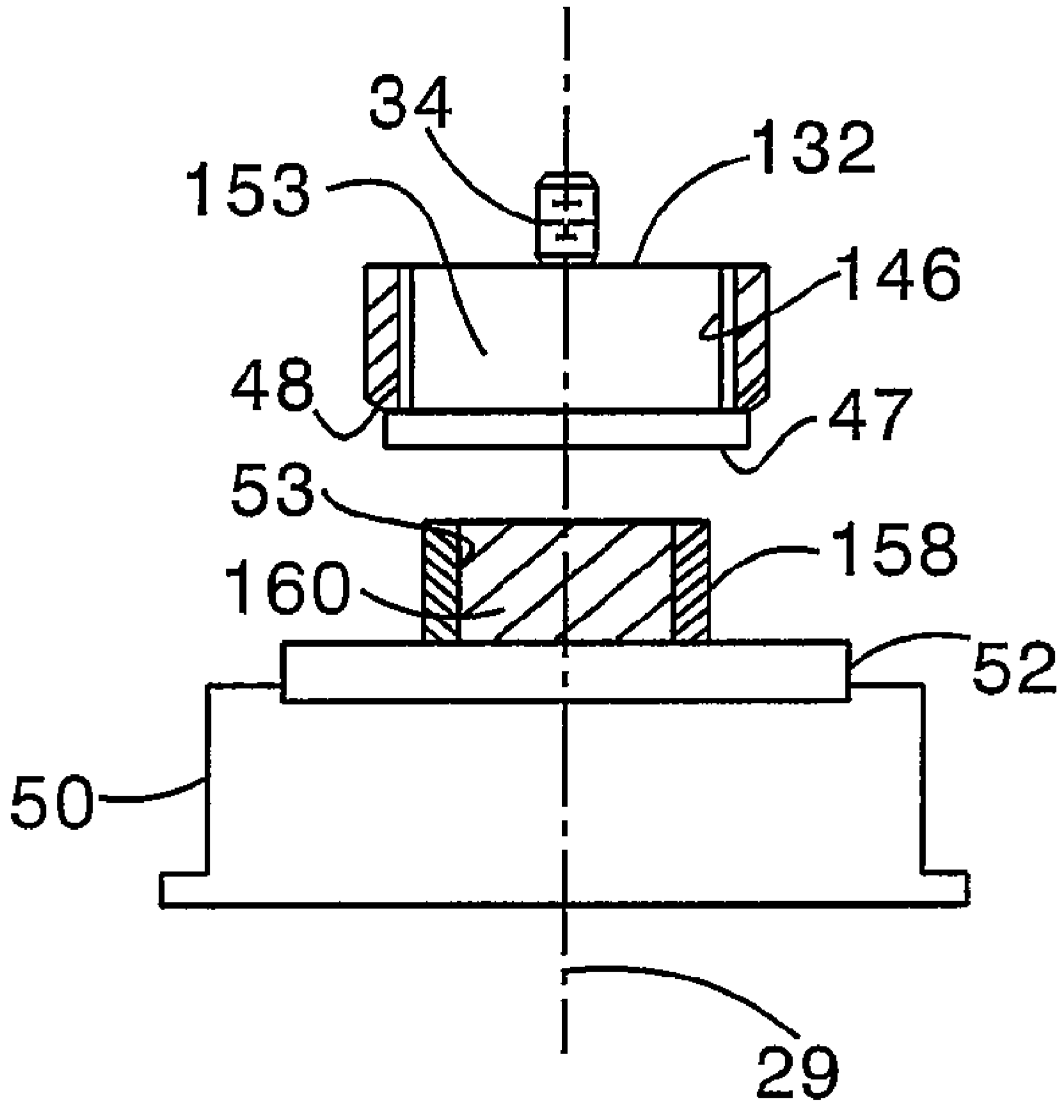

Fig. 3

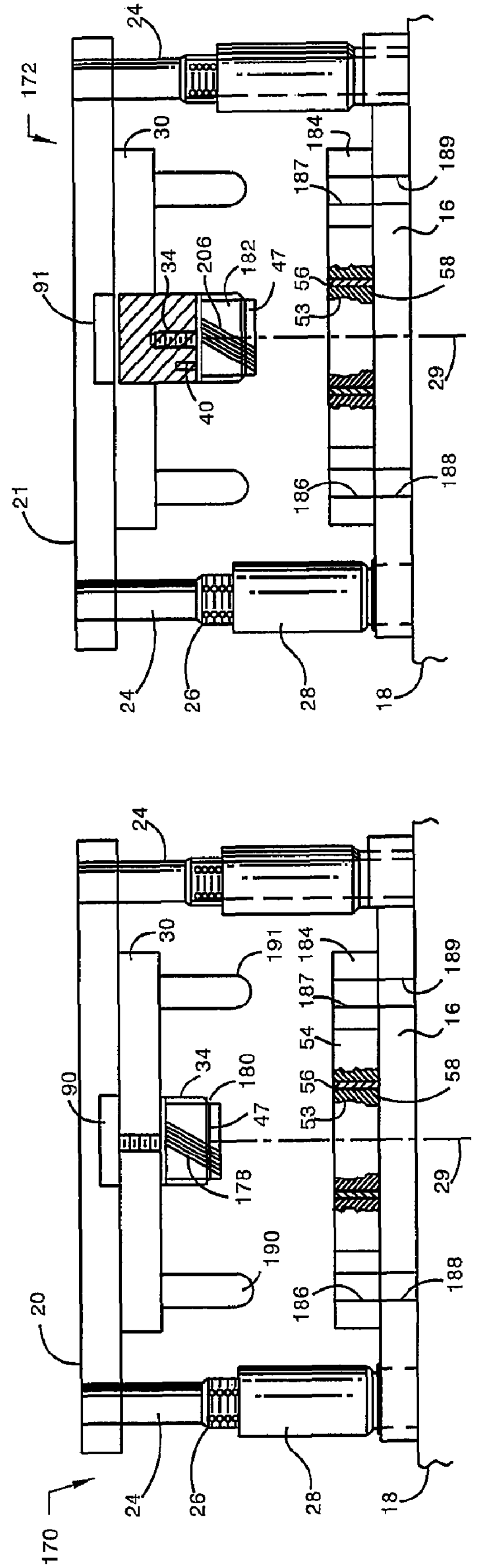
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Fig. 4

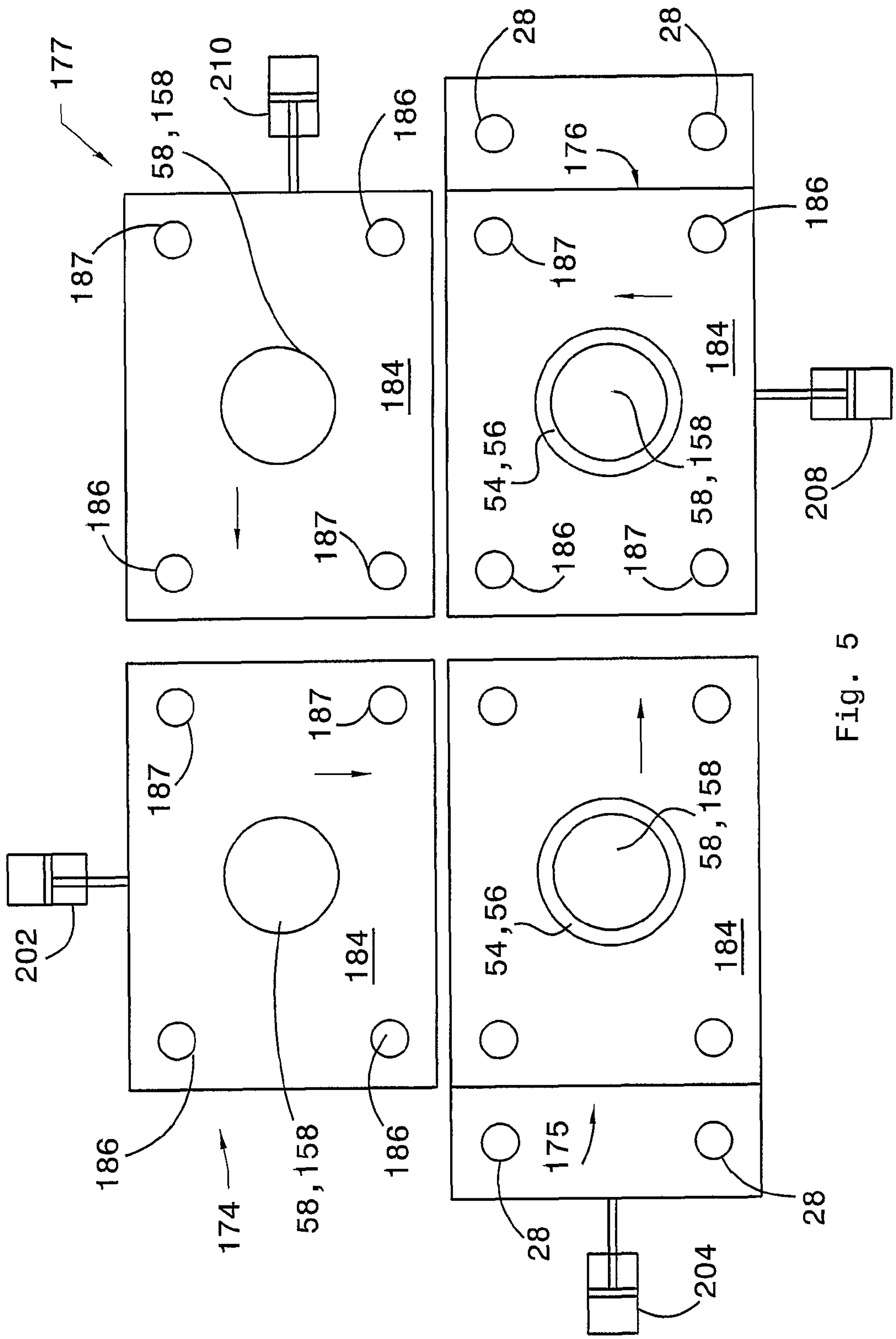

Fig. 5

MULTI-STATION DIES FOR EXTRUDING TEETH

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to extruding teeth, such as gear teeth or spline teeth, and more particularly to use of multi-station tooling for extruding helical teeth in a workpiece, such as a gear blank.

2. Description of the Prior Art

Planetary gear units of the type used in automotive transmissions include ring gears having internal helical teeth rather than straight gears even though helical gear teeth are more difficult to form. The internal gear teeth must be formed with very precise dimensions and spacing in order to perform correctly.

Machining helical gears requires expensive tooling and equipment. Current processes for forming helical teeth include broaching, shaper cutting, grinding and hobbing, all being slow processes and requiring expensive capital equipment.

Back extrusion of internal splines or helical gears is much faster, but sometimes cannot produce in one operation a complex involute tooth profile to the required dimensional accuracy. Conventional back extrusion techniques produce tooth profiles that are accurate over most of the tooth shape, but are not within specification in certain regions due to difficult geometry or failure to fill certain volumes with metal during the forming process.

A source of noise produced by transmission gearing is produced by tooth-to-tooth interactions among gears during service operation. Noise sources have been shown to result from out-of-round condition of ring gears and from surface characteristics of the mating gear teeth.

Gears having similar surface finishes can produce vibration that results in audible noise. To reduce noise, gear makers strive to achieve tooth surfaces that are very smooth and precise. Cost of gear tooth finishing has increased as efforts to reduce audible gear noise have accelerated. Gear finishing processes, such as hobbing, broaching and grinding, all produce gears with tooth surfaces that are characteristic of the process and are very similar tooth-to-tooth.

A need exists in the metal forming industry for a method that forms gear teeth at high productivity rates having a completely formed tooth profile that meets a precise accuracy standard for dimensions and tolerances and produces a random and irregular surface finish on each tooth that is dissimilar to the surface finish of the mating teeth.

SUMMARY OF THE INVENTION

A system for extruding teeth in a workpiece includes a first mandrel supported on a first die including first die teeth that produce partially formed teeth on the workpiece as the first die teeth are extruded into the workpiece by the first die, a second mandrel supported on a second die and including second die teeth that produce fully formed teeth on the workpiece as the second die teeth are extruded into the workpiece by the second die, and a transfer system for supporting and carrying the workpiece from a first station to a second station.

A method for extruding teeth in a workpiece includes providing a first die and a second die, each having a set of die teeth, producing partially formed teeth on the workpiece by extruding first die teeth into the workpiece using the first press, and producing fully formed teeth on the workpiece by extruding second die teeth into the workpiece using the second press.

Certain automotive transmission gears, such as helical ring gears, are difficult to form by extrusion methods due to the involute tooth profile. The multi-step extrusion method makes full tooth shape generation possible and enables forming complex involute geometries at high productivity rates, which, otherwise, would be difficult or impossible with conventional gear machining technology.

Extruded surface finishes can be made to vary from tooth-to-tooth or in regions around the finished product. This provides designers an opportunity to incorporate specific surface characteristics to minimize gear tooth noise and provides surface features that can be filled with lubricant to reduce friction or to produce asymmetric tooth profiles to improve performance.

The scope of applicability of the preferred embodiment will become apparent from the following detailed description, claims and drawings. It should be understood, that the description and specific examples, although indicating preferred embodiments of the invention, are given by way of illustration only. Various changes and modifications to the described embodiments and examples will become apparent to those skilled in the art.

DESCRIPTION OF THE DRAWINGS

The invention will be more readily understood by reference to the following description, taken with the accompanying drawings, in which:

FIG. **1** is a front view of an extrusion press equipped with a servo motor for forming internal helical gear teeth on a gear blank;

FIG. **2** is front view of a mandrel used in the extrusion press of FIG. **1**;

FIG. **3** is front view of a mandrel and die base used to extrude external helical gear teeth in a gear blank;

FIG. **4** is a front view of a two extrusion presses for forming helical gear teeth on a gear blank; and

FIG. **5** is a plan view of four stations in a path traveled by a shuttle that transports a gear blank to and from the extrusion presses of FIG. **4**.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIGS. **1** and **2**, an extrusion assembly **12**, mounted in a conventional hydraulic press **14**, includes a lower die plate **16**, resting on a base portion **18** of the press **14**, and an upper die plate **20**. Die guide posts **24** extend between upper die plate **20** and lower die plate **16**. One end of each die guide post **24** is fixed to upper die plate **20**; the opposite end of each die guide post **24** has a ball bearing cage **26** attached to it. Affixed to lower die plate **16** are guide bushings **28**, with each guide bushing **28** aligned with one ball bearing cage **26**. Ball bearing cages **26** telescopically slide into their respective guide bushings **28** to allow axial movement of upper die plate **20** relative to lower die plate **16**, minimizing friction and maintaining the two die plates **16**, **20** mutually parallel. The assembly **12** is concentric with and translates along an axis **29**.

A support plate **30**, guided on the guide posts **24**, is secured to the upper die plate **20** for vertical movement with plate **20** along axis **29**. A mandrel **32** is fastened to support plate **30** by a bolt **34**, which slips through a bore **36** in the center of mandrel **32** and engages a tapped screw thread in support plate **30**. Dowels **38** mate both with dowel holes **40** in support plate **30** and corresponding dowel holes **42** in mandrel **32**. Mandrel **32** is formed with external die teeth **46**, a lead surface **47**, and a single step **48**, which is preferred to a multiple-step mandrel. If the workpiece **58**, which is to be formed with internal or external helical gear teeth, has features which are difficult to form in a single step, then a multi-step mandrel may be needed since it has multiple sets of teeth with increasing precision to distribute the workpiece material more accurately to the desired shape. This also contributes to longer die tooth life. The helix angle of die teeth **46** is the same as that desired in the gear to be formed from the workpiece.

A load cell **50**, mounted on lower die plate **16**, includes force sensors mounted within it and electrically connected to a controller. Load cell **50** senses the magnitude of load and torque applied to it during the forming process. If the load is out of predetermined ranges of these parameters, then the press will stop the forming operation so that the press equipment can be checked. Load cell **50** is optional, and the extrusion process can be conducted without this piece of equipment, if so desired.

Mounted on load cell **50** is a die base **52**. A retainer ring **54**, mounted on die base **52**, has a cylindrical central cavity. A hardened sleeve insert **56**, fitted within the retainer ring **54**, surrounds the workpiece gear blank **58**. The die base **52** supports the gear blank **58** axially during the forming process. Retainer ring **54**, sleeve insert **56** and gear blank **58** are located concentric with axis **29** and mandrel **32**. The gear blank is formed with a cylindrical central cavity **53** that is aligned with axis **29**

A typical gear blank **58** includes an annular shell of precise internal diameter, in which the internal helical gear teeth will be extruded during the forming process, and a lip **60** protruding from the inner diameter at the blind end of the gear blank **58**. FIG. **1** shows the gear blank **58** inserted into the sleeve insert **56**.

A servo motor **90**, secured to upper die plate **20**, faces toward mandrel **32**, and has its shaft driveably connected to the mandrel, such that the servo motor and the mandrel rotate about axis **29** as a unit in response to control signals produced by a controller **92**.

Electronic signals **94**, produced by load cell **50** and representing the magnitude of the extrusion force and torque and the speed of press **14** are supplied to controller **92** as input. Electronic signals **96** produced by sensors **98** representing the angular displacement of mandrel **32** and the rotor of servo motor **90** from a reference position about axis **29**, and the speed of motor **90** are supplied to controller **92** as input. Electronic signals **100** produced by sensor **102** representing the angular displacement of workpiece **58** from a reference position about axis **29** are also supplied to controller **92** as input.

Controller **92** preferably includes an electronic microprocessor **104**, electronic memory **106**, and signal conditioning circuits **108**, which communicate mutually and with an output **110** over a data bus **112**. The memory contains a control algorithm, which is executed using variables represented by the input signals and is programmed to produce many different helical gear lead angles and continually adjusts to deviation from expected behavior of the press **14**.

Control signals **114** are carried from the output **110** of controller **92** to a servo motor control (not shown), which actuates servo motor **90** to rotate about axis **29** in response to the control signal produced by controller **29**. Similarly, controller **92** causes the assembly **12** to translate vertically along axis **29**.

The extrusion assembly **12** is used in a cold extrusion process for forming internal helical teeth in gear blanks **58**, with tight control of lead accuracy.

In operation, a gear blank **58** is inserted into ring insert **56** with its open end facing mandrel **32**. Hydraulic press **14** is activated and forces the upper die plate **20** downward toward lower die plate **16**, guided by die guide posts **24**.

This axial translation carries mandrel **32** toward gear blank **58** such that the lead surface **47** enters the central opening **53** in the workpiece **58**. Servo motor **90** causes mandrel **32** to rotate about axis **29** to a desired angular position, at which the helical die teeth **46** on the external surface of mandrel **32** first contact the gear blank workpiece **58**. When the mandrel **32** is in its desired angular position, hydraulic press **14** is actuated to continue its axial translation and servo motor **90** is actuated to rotate at a speed that is related to the speed of its axial translation such that the internal gear teeth are formed on the workpiece **58** with the desired helix angle.

Die teeth **46** on mandrel **32** engage the inner surface of gear blank **58** and move downward into the material of the workpiece with a helical motion supplied by the programmed servo motor as they are forced into the gear blank, thereby forming helical gear teeth. When the predetermined depth of finished gear teeth is reached, hydraulic press **14** stops pressing on upper die plate **20** and retracts the upper die plate **20** and mandrel **32**. The servo motor reverses the helix motion of the mandrel and exerts forming forces on the opposite side of the gear flank which wasn't fully formed with the downward motion of the press ram.

This movement causes mandrel **32** to withdrawal upward and to lift the workpiece **58** from the surface of to die base **52**. A box stripper **120**, secured to the die base **52**, contacts the upper surface **122** of the workpiece **58** forcing it from the mandrel **32** and allowing the mandrel to withdraw from the extruded gear. The motion of withdrawal will precisely follow that of insertion, thereby reducing the risk of nicking or deforming any of the gear teeth during removal of mandrel **32** from the finished ring gear.

The finished ring gear is then removed from press **14** and another gear blank **58** is inserted in its place preparatory to repeating the forming process. Because the travel distance of the press **14** is short, the length of the cycle period is short time and throughput is increased substantially over conventional techniques.

Although the extrusion process has been described with reference to external helical die teeth **46** on the workpiece **58** being used to extrude internal teeth on the workpiece **58**, as FIG. **3** illustrates, if external helical gear teeth are to be extruded on a workpiece **158**, a mandrel **132** is formed with a central cylindrical cavity **153**, which surrounds the outer surface of the workpiece **158** and is aligned with axis **29**. The inner surface of workpiece **158** is supported by a cylindrical plug **160** located in the central, cylindrical cavity **53** of the workpiece. The inner surface of mandrel **132** is formed with helical die teeth **146**. The servo motor **90** is driveably connected to mandrel **132** and rotates the mandrel to the required helix gear tooth angle as the press **14** forces the die teeth **146** axially into and through the wall of the workpiece **158**, thus forming external helical gear teeth on the outer surface of the workpiece or gear blank **158**.

To obtain extruded gears, which consistently meet dimensional requirements, a multi-step forming process is used. FIGS. **4** and **5** illustrate a multi-station extrusion operation that includes a first hydraulic press **170**, where semi-finished helical teeth are formed in a gear blank **58**, **158**, and a second hydraulic press **172**, where the teeth are finish-formed and an irregular surface finish is produced on the flanks of the teeth.

The presses **170**, **172** are substantially identical to the hydraulic press shown in FIG. **1** including the servo motor **90**.

The first press **170** partially forms teeth on the blank **58**, **158** in a first step. A transfer line then moves the lower die to the second station, which finish-forms the surfaces being extruded during a second step following the first step.

FIG. **5** illustrates movement of the gear blank **58**, **158** among shuttle stations **174**, **175**, **176**, **177**, upon being actuated by a shuttle mechanism, which maintains the position and orientation of the gear blank as required to meet final product requirements.

Positioning of the gear blank **58**, **158** is maintained constant relative to axis **29** and forming mandrels **180**, **182** by the addition to presses **170**, **172** of a moveable shuttle **184**, which is formed with bored holes **186**, **187**, each of which is aligned with a respective hole **188**, **189** in the lower die plate **16**. Support plate **30** carries pins **190**, **191**, which depend from its lower surface. When the upper die plate **20** of press **170** is lowered sufficiently, pins **190** enter the aligned bores **186** and **188**. When the upper die plate **21** of press **172** is lowered sufficiently, pins **191** enter aligned bores **187** and **189**.

In operation, the gear blank **58**, **158** is placed on a shuttle **184** at load-shuttle station **174**, and a piston-cylinder assembly **202** is actuated to move the shuttle **184** to the second station **175** at press **170**. There, retaining ring **54** and hardened sleeve **56** are placed around the gear blank **58**, or plug **160** is inserted into the cavity **53** of the blank **158**, depending on whether internal or external helical gear teeth are to be extruded. The upper die plate **20** is lowered, die teeth **178** of mandrel **180** are extruded in a semi-finished condition in the surface of the gear blank partially forming the helical gear teeth, and mandrel **180** is raised from the blank.

Then a second piston-cylinder assembly **204** is actuated to move shuttle **184** to the third station **176** at press **172**. There, the upper die plate **21** of press **172** is lowered, die teeth **206** of mandrel **182** are extruded in a finish-formed condition into the surface of the gear blank **58**, **158** forming the helical gear teeth, and mandrel **182** is raised from the blank.

A third piston-cylinder assembly **208** is actuated to move shuttle **184** to the unload-shuttle station **177** where the gear blank **58**, **158** is removed from the shuttle **184**. There, a fourth piston-cylinder assembly **210** is actuated to move shuttle **184** to the load-shuttle station **174**, where a second gear blank is placed on the shuttle. The same procedure is repeated on the second gear blank at each of the stations **174-177**.

The die teeth **178**, **182** on forming mandrels **180**, **182** are essentially the inverse of the teeth to be extruded in the workpiece. Each die tooth on a mandrel produces a corresponding tooth on the workpiece, and the flanks of at least some of the fully formed extruded teeth are custom surface finished.

Surface striations, such as minute grooves, scratches, or channels, can be applied as needed to the flanks of the extruded teeth to reduce gear noise. To counteract vibration resonance, a varied, irregular surface finish is produced in zones in the flanks of the fully formed extruded teeth. For example, on teeth located in an angular range from 0 to 90 degrees about axis **29**, a first surface finish is produced that is different from the surface finish produced on teeth in an angular range from 180 to 270 degrees around axis **29**.

To apply specific finishes to individual teeth or to angular zones of the fully formed extruded teeth on the workpiece **58**, **158**, preferably mandrel **182** is made with surface-producing details in those regions. Mandrel **182** is ground according to a specific grinding protocol, which places on its die teeth in a first angular zone about axis **29** a first surface finish, and places on its die teeth in a second angular zone about axis **29**, different from the first zone, a second surface finish, different from the first surface finish. As mandrel **82** is extruded into the workpiece **58**, **158**, the first and second surface finishes are transferred to the flanks of the extruded teeth in each respective zone. In this way, a first portion of the extruded teeth on the workpiece will conform to the first surface finish, and a second portion of the extruded teeth will conform to the second surface finish.

Alternatively, to obtain the same low gear noise characteristics, a post forming operation, such as acid etching, laser surface treatment, surface alteration using abrasive high pressure water jets, sand blasting or a combination of these, is preferably performed on the flanks of the extruded gear teeth at station **176** or **177**.

In accordance with the provisions of the patent statutes, the preferred embodiment has been described. However, it should be noted that the alternate embodiments can be practiced otherwise than as specifically illustrated and described.

The invention claimed is:

1. A system for extruding teeth in a workpiece comprising:

a first mandrel supported on a first press and including first die teeth that produce partially formed gear teeth on the workpiece as the first die teeth are extruded into the workpiece by the first press;

a second mandrel supported on a second press and including second die teeth that produce fully formed gear teeth on the workpiece as the second die teeth are extruded into the workpiece by the second press; and

a transfer system for supporting and carrying the workpiece from the first press to the second press.

2. The system of claim **1** wherein the transfer system further comprising:

a first station where the workpiece is placed on a shuttle; and

a first actuator that moves the shuttle from the first station to a second station at the first press.

3. The system of claim **2** wherein the transfer system further comprising:

a second actuator that moves the shuttle from the second station at the first press to a third station at the second press.

4. The system of claim **3** wherein the transfer system further comprising:

a third actuator that moves the shuttle from the third station at the second press to a fourth station.

5. The system of claim **4** wherein the transfer system further comprising:

a fourth station where the workpiece is removed from the shuttle; and

a fourth actuator that moves the shuttle from the fourth station to the first station.

6. The system of claim **1** wherein the first die teeth of the first mandrel are helical die teeth that produce partially formed helical teeth on the workpiece as the first die teeth of the first mandrel are extruded into the workpiece by the first press.

7. The system of claim **1** wherein the first die teeth of the first mandrel are helical die teeth that produce partially formed internal helical teeth on the workpiece as the first die teeth of the first mandrel are extruded into the workpiece by the first press.

8. The system of claim **1** wherein the second die teeth of the second mandrel are helical die teeth that produce fully formed helical teeth on the workpiece as the second die teeth of the second mandrel are extruded into the workpiece by the second press.

9. The system of claim **1** wherein the second die teeth of the second mandrel are helical die teeth that produce fully formed internal helical teeth on the workpiece as the second die teeth of the second mandrel are extruded into the workpiece by the second press.

10. The system of claim **1** wherein:

the first press further includes a first servo motor driveably coupled to the first mandrel for rotating the first mandrel about the axis as the first die teeth are extruded into the workpiece; and

the second press further includes a second servo motor driveably coupled to the second mandrel for rotating the second mandrel about the axis as the second die teeth are extruded into the workpiece.

11. A method for extruding teeth in a workpiece comprising the steps of:

(a) providing a first press and a second press, each having a set of die teeth;

(b) producing partially formed gear teeth on the workpiece by extruding first die teeth into the workpiece using the first press; and

(c) producing fully formed gear teeth on the workpiece by extruding second die teeth into the workpiece using the second press.

12. The method of claim **11** further comprising moving the workpiece from the first press to the second press after using the first press.

13. The method of claim **11** further comprising the steps of:

placing the workpiece on a shuttle at a first station;

moving the shuttle from the first station to a second station at the first press;

moving the shuttle from the second station to a third station at the second press;

moving the shuttle from the third station to a fourth station; and

removing the workpiece form the shuttle.

14. The method of claim **11** further comprising forming striations on the flanks of at least some of the fully formed teeth.

15. The method of claim **11** further comprising the steps of:

producing a first surface finish on flanks of fully formed teeth located in a first angular zone about an axis; and

forming a second surface finish, different from the first surface finish, on the flanks of fully formed teeth located in a second angular zone about the axis.

16. The method of claim **11** further comprising the steps of:

forming a first surface finish on the second die teeth in a first angular zone about an axis; and

forming a second surface finish that is different from the first surface finish on the second die teeth in a second angular zone about the axis.

17. The method of claim **11** further comprising the step of:

after using a mandrel to extrude the fully formed teeth in the workpiece, producing an irregular surface finish on flanks of the extruded fully formed teeth.

18. The method of claim **11** further comprising the step of:

after using a mandrel to extrude the fully formed teeth in the workpiece, producing a random, irregular surface finish on the flanks of the extruded teeth by performing one of acid etching, laser surface treatment, surface alteration using abrasive high pressure water jets, and sand blasting.

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