Ausrolling, A Technology Developing to Meet the Demands of Today

オーースローリングによる歯車の熱間仕上げ転造

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Abstract

As fuel efficiency and power to weight ratios continue to increase for the automotive and aerospace industries, gear systems require increased power density to meet these challenges. Gears fail fundamentally due to both bending and contact fatigue. National Broach and Machine Company, under contract to the Applied Research Laboratory at Penn State University and in conjunction with MTS controls and Contour Induction Hardening, has developed a dual die gear rolling system. This system has the capability to heat treat and finish gears with geometries up to AGMA class 12 without typical heat treatment distortion seen in common processes. This system coupled with our new root rolling technology can improve both contact and bending fatigue by an order of magnitude.

摘要

自動車産業および航空機産業における燃費向上，出力向上に対する要求は相変わらず重要で，このため，歯車系統における出力密度向上への取組みもますます重要になってきている。
基本的には，歯車の損傷は歯車同志の噛み合によって生じる曲げおよび接触に起因するものである。
National Broach & Machine Company は，Penn State University の The Applied Research Laboratory および MTS controls and Contour Induciton Hardning とともに，2 ロールダイスによる歯車転造システムを開発した。
このシステムでは歯車の熱処理と仕上げ加工が可能で，通常の工程で用いられる特別な歪み取り焼鈍を行わなくても，AGMA Class 12 程度の高い歯車精度が得られる。
このシステムでは，新たに開発した歯底の転造技術との組み合わせで，歯面強度および曲げ強度の両方を飛躍的に向上させる画期的な歯車仕上げ技術である。

1. Traditional Gear Manufacturing Process

Conventional gear manufacturing uses hobbing to cut rough gear geometry into a blank and the finish form is shaved from the rough cut. The part is then carburized in a furnace and quenched in oil. The part can be used, or depending on quality requirements, may require additional operations to improve distortions in geometry following the heat treatment process.

2. Process Induced Failure Modes

Typically, gears fail prematurely in operation due to two phenomena: tooth bending fatigue or tooth contact fatigue. These can be influenced by many variables including: metallurgical variation, manufacturing errors, thermal distortion, and basic gear design.

Bending fatigue can best be compared to a group of beams protruding from the hub of a gear. For simplicity, each beam can be looked at individually with a force pushing down on the end of the beam. As the gear rotates, teeth (beams) from the mating gear repeatedly push down on the beam. As the load (force) on the beam increases the deflection of the beam also increases. This repeated loading creates what is known as cyclic bending fatigue. The manufacturing process which creates the geometry in the root of the gear tooth leaves small errors which result in stress risers within the area where bending occurs. These stress risers reduce the effective life of each tooth

Contact fatigue results when forces perpendicular to the tooth contact surface exceed the ultimate strength of the material structure. Errors in the surface, both in form and finish, will result in instantaneous high loading at the point of these errors, creating what is called a pit. As the surface erodes under this mechanism the errors increase, resulting in higher and higher contact loads which accelerate the failure. The conventional finishing process of shaving leaves small diagonal errors. Heat treatment generates distortion and metallurgical variation. Both of which result in increased contact loads.

3. Ausform Gear Process

The ausform process takes the hobbed gear blank and heats it to the austenite transformation temperature, then cools it quickly to the low end of the austenite range (approximately 500°F) just prior to the formation of martensite (**Figure 1**). While in the austenite phase the work piece is extremely soft, typically softer than raw unhardened material at room temperature. The work piece is then maintained at this temperature while being rolled to finish gear tooth form and size. Using full form rolling dies also minimizes tooth root geometry errors. The work piece is then cooled to room temperature. Because the final form is finished at a low temperature, little or no distortion occurs in the work piece when it transforms to a hard ausformed martensite structure at the time it is cooled to room temperature.

The ausforming process was developed several decades ago. At that time it was proven that the ausformed martensite substantially increased the strength of the work piece as compared to conventional heat treated martensite. Improvement in tensile and yield strength

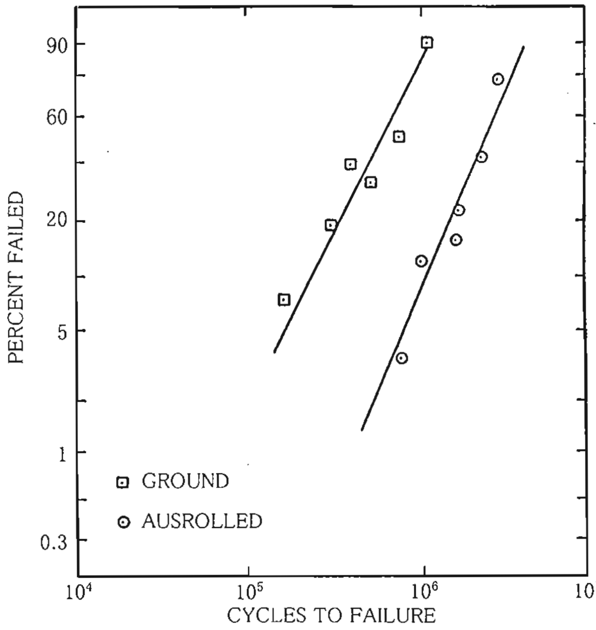

Figure 2 Comparison of fatigue life between ausrolled and ground EX15 steels

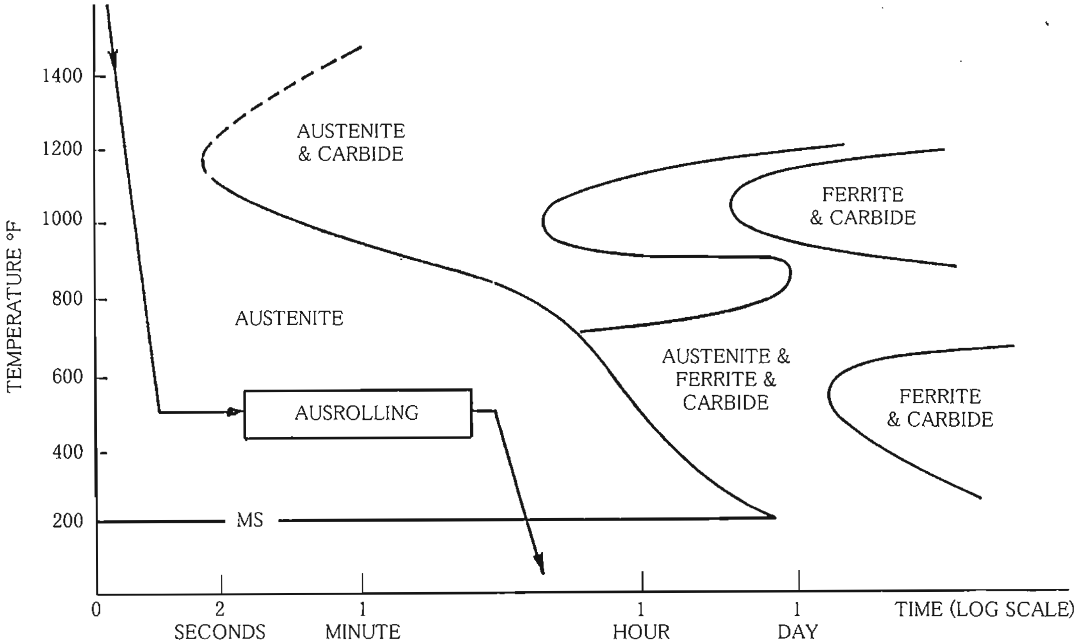

Figure 1 Heating pattern in the ausforming process

Table 1 Nominal composition of M50 steel and Pyrowear 53

	C	Mn	Si	Cr	Ni	Mo	Cu	V
Pyrowear 53	*0.1*	*0.35*	*1.0*	*1.0*	*2.0*	*3.25*	*2.0*	*0.1*
EX-15	*0.2*	*1.0*	*0.3*	*0.5*	--	*0.2*	--	--

was seen in excess of 30%. B10 fatigue life of M50 steel in rolling contact fatigue specimens showed a 600% improvement. Research at both General Electric and NASA Lewis also demonstrated significant increases in B10 fatigue life. The effects of ausforming on EX15 steel at 450ksi contact stress can be seen in Figure 2. Similar improvements have also been achieved in materials such as Pyrowear 53, 9310, and powder metal steels.

Nominal composition of M50 steel and Pyrowear 53 are shown in Table 1.

However, even with these improvements, few attempts were made to successfully implement the new technology. This was fundamentally due to the high deformation loads necessary for plastic deformation of the work piece and the ability to control part accuracy. The ausroll process produces a finished product and should be the last step in the manufacturing process. At the time it was developed the process did not produce the necessary product accuracy without supplemental finishing operations.

4. Ausform System Strategy

These and other design issues required significant technical consideration to implement this process. Safety was also of prime concern due to the volume and temperature of the ausforming oil. The design target was to build a manufacturing system capable of ausforming both helical and spur gears with face widths of up to 80 mm and diameters of up to 180 mm. An AGMA class 14 gear was the targeted quality. This is necessary to meet the requirements of the aviation and aerospace industry. Productivity was not a consideration

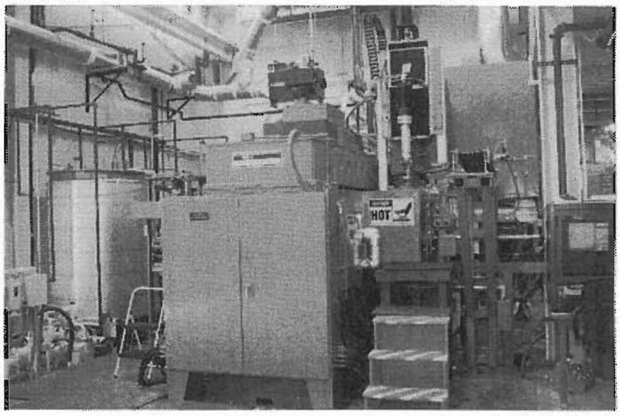

Figure 3 Photograph of the ausroll gear finishing machine

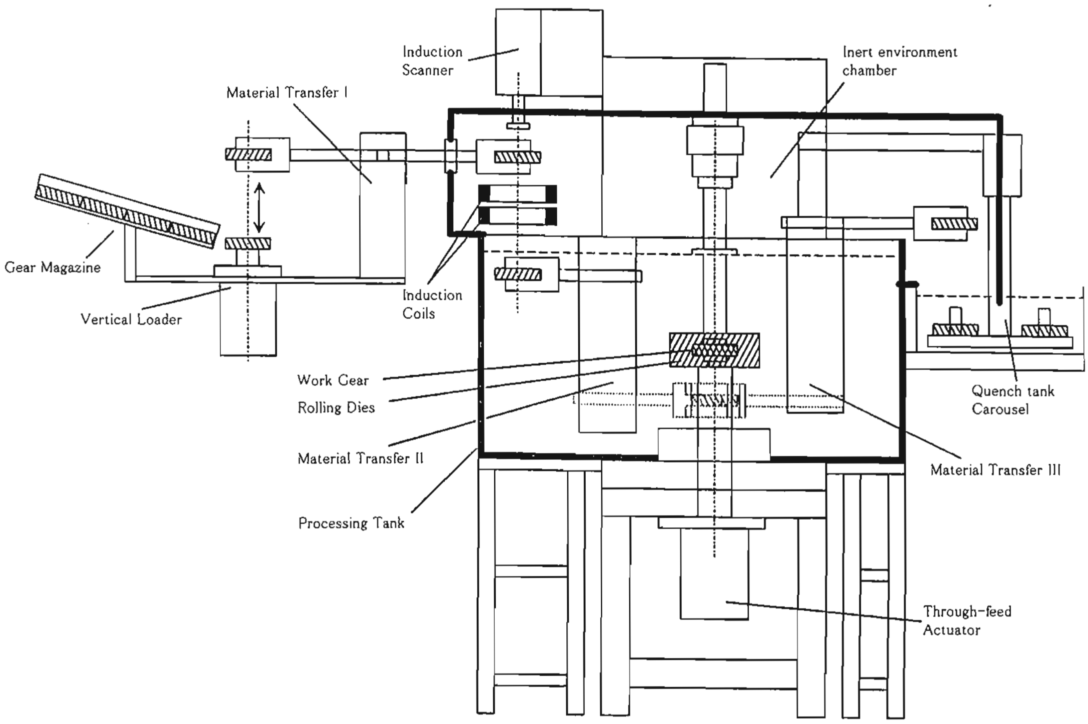

Figure 4 Schematic drawing of the ausroll gear finishing machine (Side view)

for this project.

The system, designed for and in collaboration with the Advanced Research Laboratory at Penn State University, consists of four basic sub systems: an induction heating unit, a 500°F quench ausforming tank, a dual die gear roller and an auxiliary final quench tank.

Photograph and schematic drawing of the ausroll gear finishing machine are shown in Figures 3 and 4, respectively.

5. Induction Heating and Marquenching

The induction heating system (Figure 5) was designed and built by Contour Induction Hardening of Indianapolis, Indiana. This system consists of both medium and radio frequency power supplies. The part is loaded to a work piece spindle where it is spun during the contour heating process, then transported from the loading position to the MF and RF heating position, and finally into the quench oil tank. The part is then unloaded to a gripper located at the end of the spindle's 18 inch stroke near the bottom of the quench oil tank.

The ausforming oil system (Figure 6) consists of an insulated tank located on the main machine frame. This tank envelopes the roll spindles and work piece spindle. A removable panel is located on one side to gain access to the spindles for service and roll die changes. A remote oil storage tank is used to heat the oil to the desired operating temperature of a maximum 550°F. The oil is pumped from the storage tank to a heater and, through a series of valves, can be directed either back to the storage tank or directly to the ausform tank. While performing, the ausforming operating oil is circulated back through the heater without returning to the storage tank. Oil flow rate, system pressure, and system temperature are monitored to maintain the desired system conditions. A range of 5°F for quench oil tank temperature control was established. The target was to maintain the operating temperature of oil in the ausforming tank within a 5°F. Safety with this system was a major concern due to the oil operating temperature and oil flash point. It was necessary to enclose this system (Figure 7) and provide a non-oxidizing atmosphere by purging the tank area with nitrogen gas. This reduces soot and minimizes the potential of an oil fire.

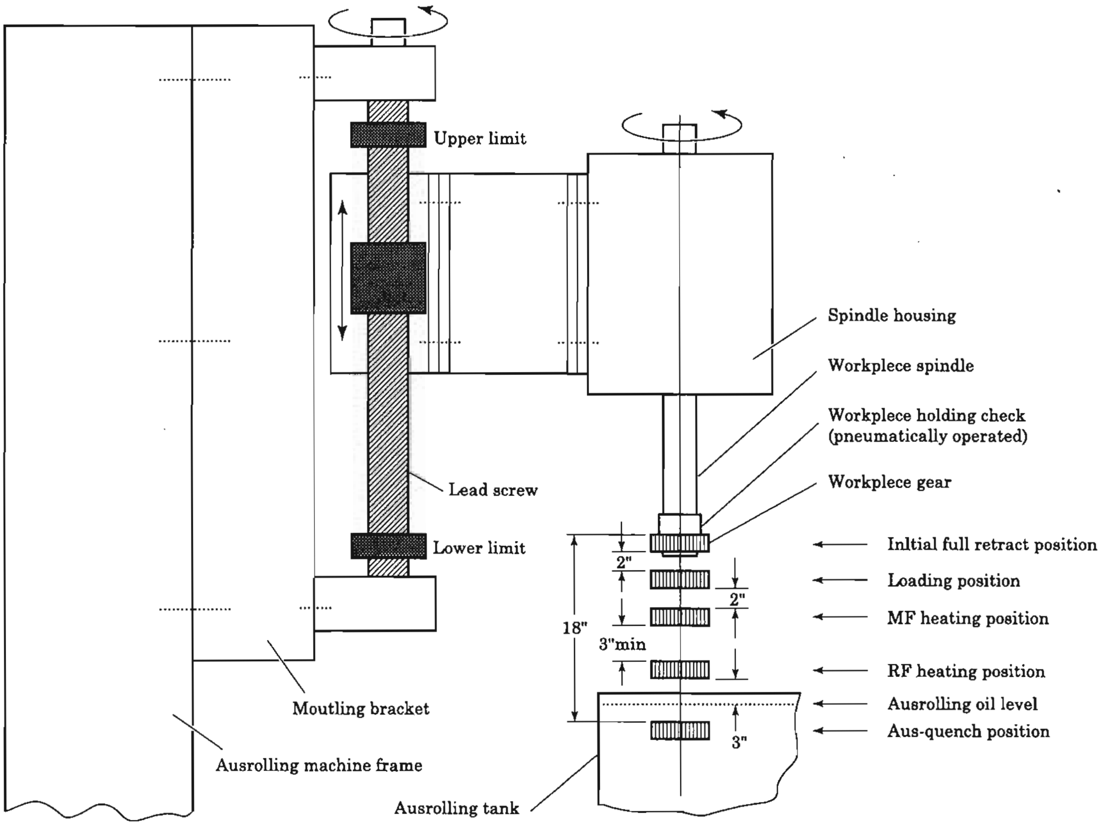

Figure 5 Induction heating spin/scan station

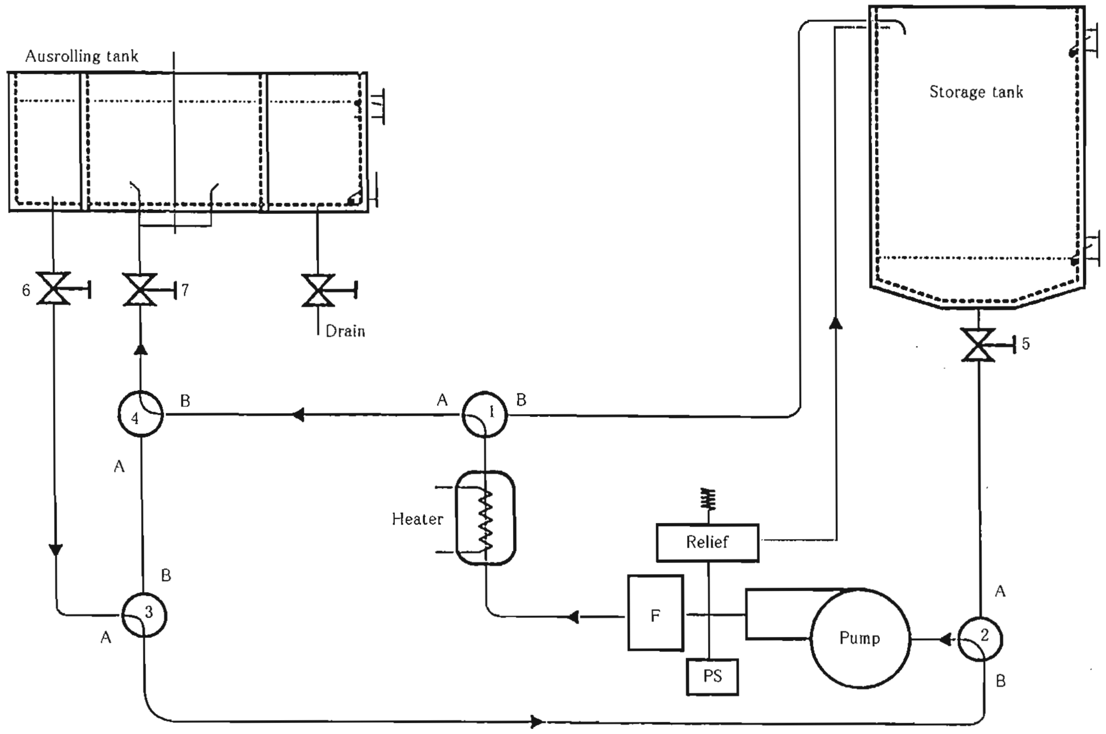

Figure 6 Ausrolling oil heating and recirculating unit

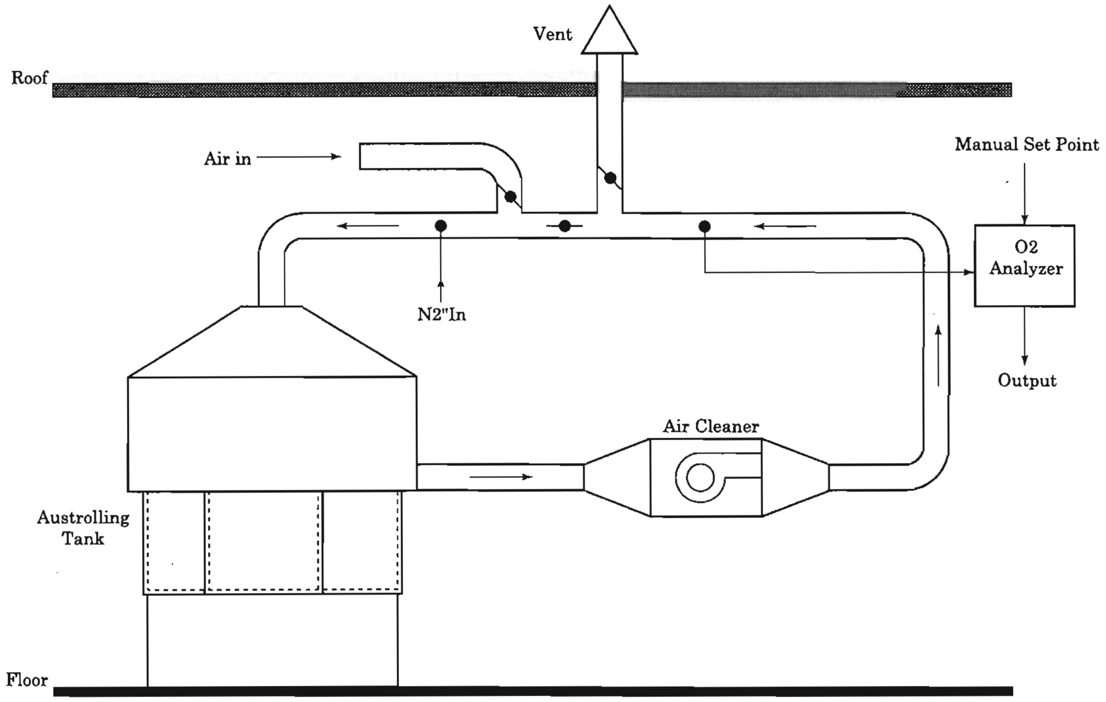

Figure 7 Nitrogen/air recirculating system

6. Rolling The Gear

The gear rolling portion of this system (Figure 8 and 9) was based on the National Broach and Machine Company RGB style dual die production gear rolling machine. Due to the elevated operating temperatures of the system, many components required additional consideration. Bearing materials were changed to special

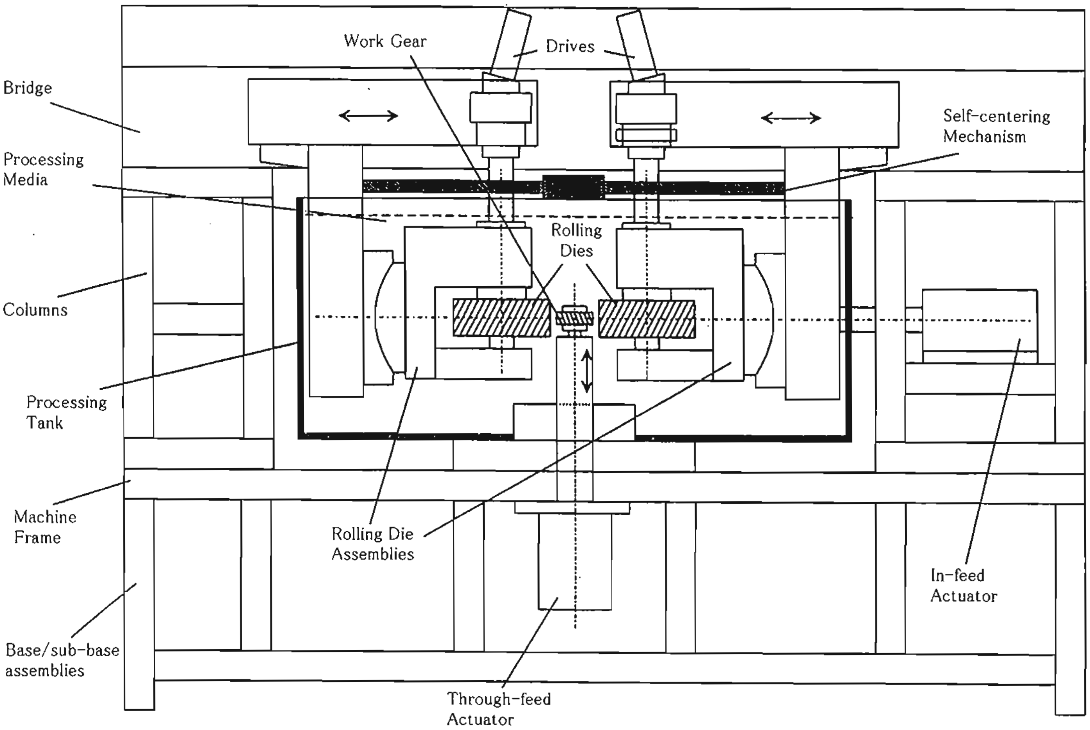

Figure 8 Ausroll finishing machine (Front view)

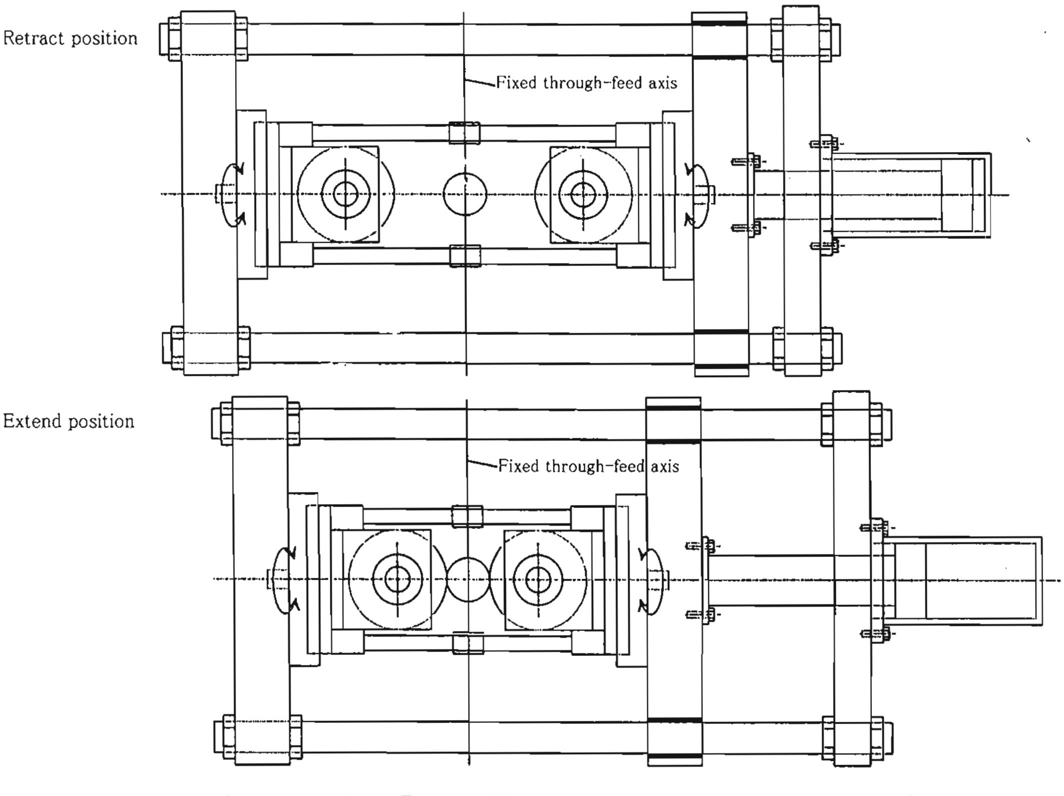

Figure 9 Infeed motion - Two end position of infeed actuator (Top view)

alloys which would not lose their hardness over time. Stringent quality standards required to meet the targeted AGMA 14 standards demanded close manufacturing tolerance fits on all spindle and adjustment systems. Provisions were made to provide cooling to all spindle assemblies minimizing any distortion of the system under operating conditions. However, it was decided that this would not be used during initial testing. Bearing and spindle fits were calculated to be correct at the design temperature of 500°F.

The roll die spindles of the machine are driven through two constant velocity joints from a common gear box located in the overhead bridge of the machine. Each die spindle possesses independent adjustability for lead, taper, and skew. The die spindles move radially to the centerline of the work piece spindle. This is accomplished through a basic scissor action which balances the rolling load between the two die spindles. The die spindles are encoded for position and monitored for pressure. The actuator utilizes servo hydraulics to achieve spindle positioning for maintaining work piece size.

The work piece spindle utilizes a collet type design to grip the bore of the work piece. The automation gripper takes the work piece from the induction hardening scan spindle on the outside diameter of the gear and places it on centerline of the through feed spindle. The spindle moves upward into the bore of the gear. The collet then clamps onto the work piece and begins to rotate in the same direction as the roll dies. The roll dies are designed with a tapered leading edge to facilitate meshing of the work piece with the roll dies. Special alloy materials were necessary for the collets. The initial collet design takes a permanent set after operating at the 500°F. After the roll die spindles attain the desired roll depth, the spindles retract, and the work piece spindle returns to the load/unload position. While the rolling operation takes place, the loader gripper returns to its load position at the induction hardener scan spindle and the unloader gripper moves to recover the finished work piece. The gripper now closes on the finished work piece and the work piece moves to a position to be picked and placed into the final quench tank.

Lubrication for the system is derived from the marquench oil itself. This is a common oil used throughout in order to maintain a common flash point and oil compatibility.

The final quench is an oil bath at room temperature. It is at this point the work piece attains its martensite structure and hardness.

7. The Rolling Dies

The basic rolling process produces a much finer surface finish compared to both shaving and grinding. A typical rolled gear has a surface finish of 4 to 6 micro inch Ra, compared to a shaved surface of 25 micro inch Ra. A good quality grind falls somewhere in between these values. These lower surface values improve the contact fatigue condition by reducing the potential for asperity contact under thin film lubrication conditions. Conventional roll die design finishes only the active tooth flank contact area. The hob tool and roll die are designed to provide a clearance at the root of the gear tooth. Full form roll finishing (**Figure 10**) simultaneously forms the active flank contact surface and the trochoidal root fillet regions of the gear teeth. As with conventional roll die design, special geometry hobbing tools are necessary to provide for uniform material to follow the proposed root fillet and active contact surfaces. The rolling die must be designed to maintain constant angular velocity between itself and the work piece to creating uniform material flow throughout the rolling engagement as shown in **Figure 11**. These unique and highly precision roll dies are manufactured on a precision form grinder. The grinding wheel is dressed using detailed profile

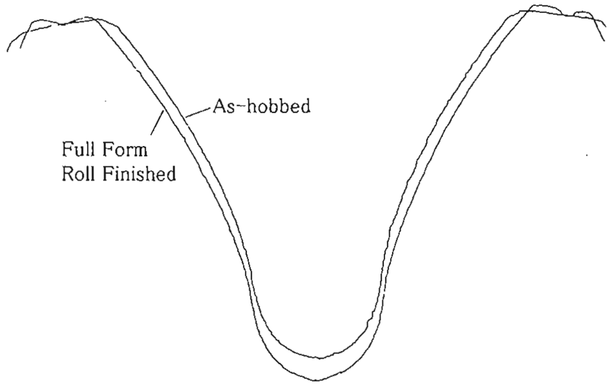

Figure 10 Tooth profile before and after ausroll finishing

coordinates to produce the necessary rolling die profile design.

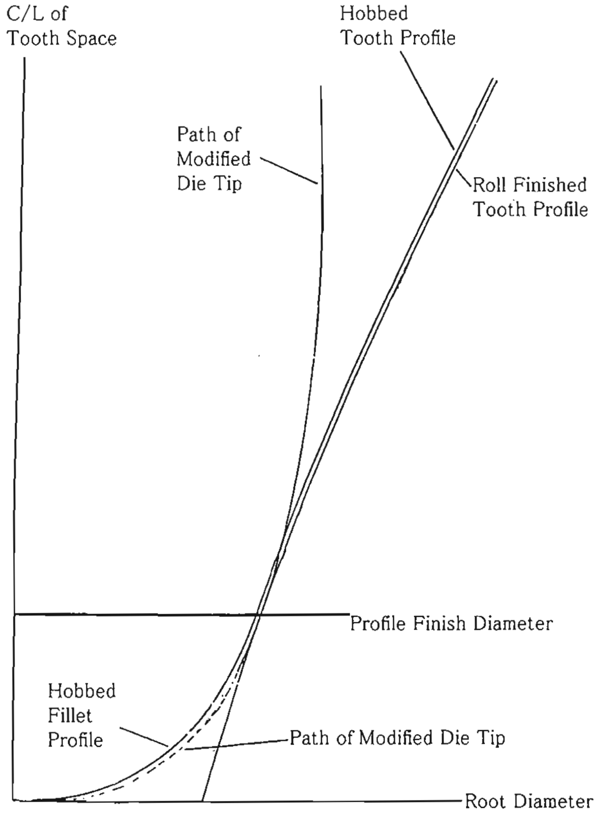

Figure 11 Hobbed fillet profile and path of die tip

8. Summary

This ausroll process utilizing the latest roll die technology offers a potential solution to increased power density in both helical and spur gears. The system as described focused on research for the aviation and aerospace industries. Testing is continuing to better understand and validate the process. Once this has been accepted and proven within these industries, activities will be directed toward its development for the automotive industry. Producing a process capable of meeting the automotive industries high volume capacity requirements will be a significant challenge.

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