

Low Cycle and Static Bending Strength of Carburized and High Hardness Through Hardened Gear Teeth

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American Gear Manufacturers Association



TECHNICAL PAPER



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Low Cycle Fatigue and Static Bending Strength of Carburized and High Hardness Through Hardened Gear Teeth

W. Pizzichil, Philadelphia Gear Corp

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ABSTRACT:

A summary of the testing methods employed and the results generated for unidirectional and reverse bending tests of very coarse and medium pitch gear teeth is presented. Actual measured stresses were compared with FEM theoretical stresses and AGMA stress numbers.

The purpose of this testing was to evaluate which type hardening method would yield a gear tooth that could carry the highest load without catastrophic breakage failure in a single, or very low cyclic load application. This testing simulated the output pinion and a planet gear for a jack-up gear drive used on oil drilling platforms. There were three separate tests conducted over a period of time.

The first test was performed statically on an actual 12 inch circular pitch pinion loaded against a rack. A second static test utilized a half scale model of a 12 CP gear tooth fillet loaded to failure in a single cycle and also cycled to failure at extremely high loads. The third test was a reverse bending test simulating a planet of a planetary gear used in the final reduction stage.

The last two tests were accomplished simultaneously for both through hardened and carburized test pieces. The results demonstrated the benefits of the relatively ductile through hardened gears and their ability to locally yield and distribute stresses without catastrophically failing in this type of application.

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**LOW CYCLE FATIGUE AND STATIC BENDING STRENGTH OF
CARBURIZED AND HIGH HARDNESS THROUGH HARDENED GEAR
TEETH**

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INTRODUCTION:

The particular application for the gear drives that were tested is to elevate off shore drilling rig platforms (jack-ups) above sea level once they have been floated to the desired drilling location, see Figure 1. The drives are fixed to the deck of the vessel. They have output pinions which mesh with racks that are attached to three moveable triangular legs at each corner of the vessel. The legs are lowered to the ocean floor and the platform is raised to the desired height.

COMMENT

This paper presents the results of actual testing performed on large scale, costly test pieces. It is recognized that there are statistical variations associated with this type of testing that make absolute conclusions unrealistic. There is no attempt made to characterize the metallurgical phenomena that governs the behavior.

LITERATURE SURVEY

The literature reveals that work has been carried out evaluating the performance of through hardened racks for jack-ups by Honda (1,2,3). There also is extensive work available relating to the failure of case hardened gears. References (4,5,6,7,8) represent a sampling of this literature. The testing presented in this paper was performed to gather data on very large carburized gears, where very little testing has been performed.

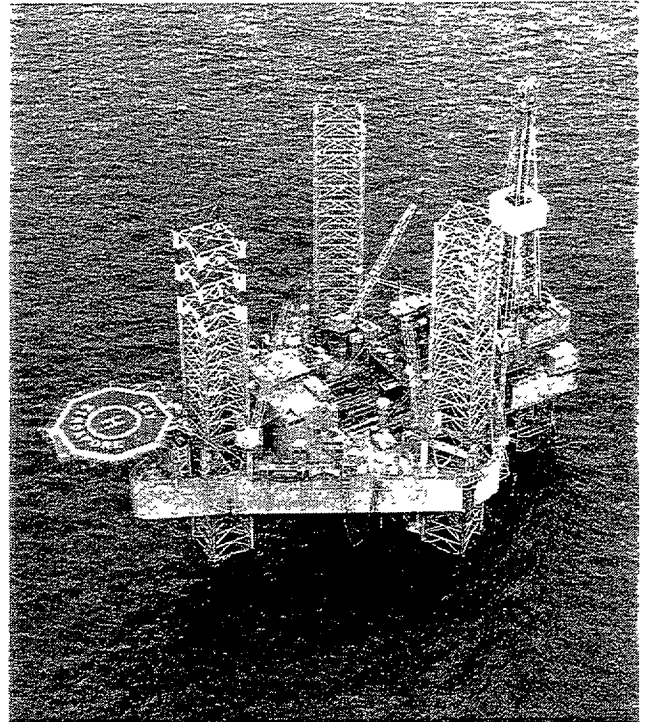


**FIGURE 1. OFFSHORE DRILLING RIG
PLATFORM (JACK-UPS)**

TEST 1

**SINGLE CYCLE BENDING FAILURE TEST (12 CP
Actual Pinion).**

TEST OBJECTIVES AND METHOD

The main objective of this testing was to determine the single cycle

ultimate fracture strength of a 7 tooth, 12 CP, 8.5 inch face width, carburized, spur pinion, loaded at the highest point of single tooth contact.

This test was necessary to determine the maximum holding capability of the pinion supporting the jack-up rig. A second objective was to evaluate the effects of load sharing in the narrow band of two tooth contacts with the mating rack. Tooth pair load sharing potential is evaluated by the transverse contact ratio parameter. The nominal, transverse contact ratio is approximately 1.1. The final objective was to determine if the mating, through hardened, rack had equal or better ultimate fracture capacity compared to the carburized pinion, when loaded at it's highest point of single tooth contact.

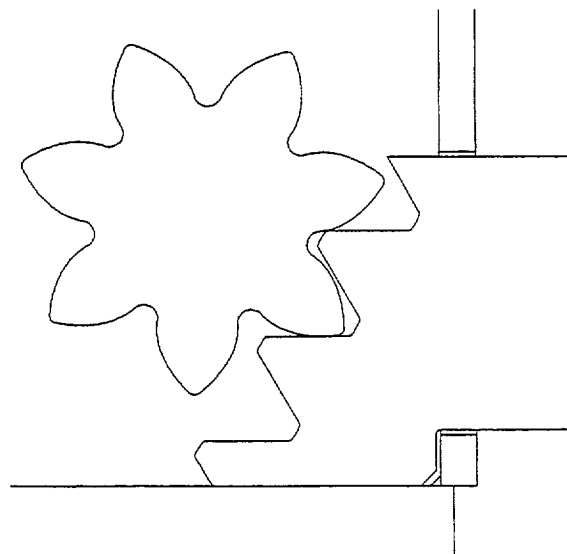


FIGURE 3

PINION TEST

Figure 2 shows the test stand that was designed to support the jack-up gear drive with it's outboard, 7 tooth pinion in a similar way that the jack tower supports the drive in the jack up rig .

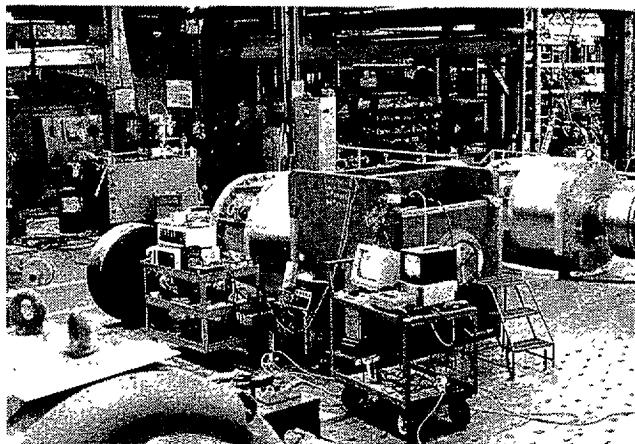


FIGURE 2. JACK-UP GEAR DRIVE TEST STAND

An actual segment of rack was installed in the test stand to mesh with the pinion, see Figure 3. This rack segment reacted the statically applied tangential load and loaded the test stand housing in a closed loop configuration and self contained the extremely large tangential force of up to 2,100,000 lbs.

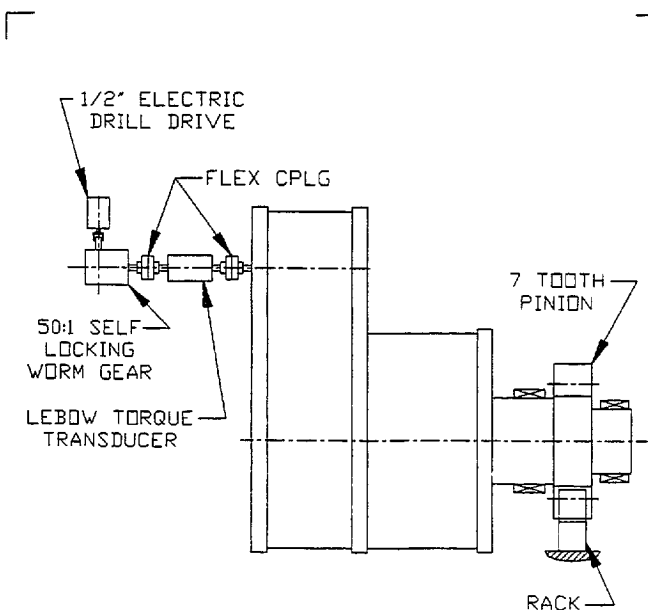


FIGURE 4

Figure 4 shows a schematic of the test drive train. The input shaft of the test gearbox was coupled to a Lebow Torque Transducer which was driven by a 50:1 ratio, self locking worm gear drive. The worm drive input was then rotated by a large 1/2 inch drive industrial drill for system loading. An input torque of 350 lb-ft at the jack-up gearbox generated the 2,000,000 lb. tangential output force via the five



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parallel shaft gear meshes and one planetary stage for a total 1765:1 gear drive ratio. The output force takes into account the frictional mesh and bearing losses. The system winds up like a large torsional spring requiring 38 full turns of the input shaft once all backlash is removed to obtain 1,600,000 lbs. tangential force on the 7 tooth pinion. The self locking worm drive held the input torque at any desired level and prevented unwinding of the geartrain. The Lebow Torque Cell was connected to a digital display calibrated to read input torque directly in foot pounds.

The 7 tooth pinion and racks were instrumented with strain gauges at, and very near the calculated critical stress area of the tooth root fillets. Four gauges were laid at each edge of the face width so that any maldistribution of load across the face width, due to misalignment, could be assessed, see Figure 5. The strain was measured with a Vishay Strain Recording Indicator.

STRAIN GAGE LOCATIONS ON PINION

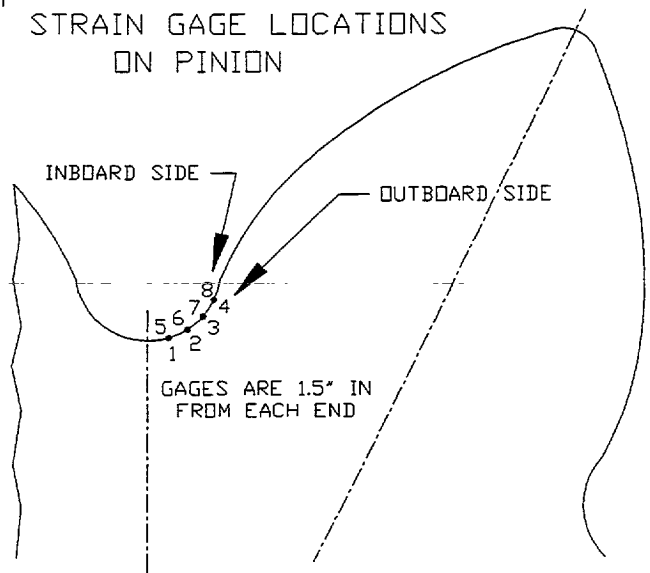


FIGURE 5

PINION MATERIAL, MANUFACTURING PROCESS AND HEAT TREATMENT

The 7 tooth output pinion was made of 17CrNiMo6, a popular European carburizing steel, which has high hardenability. The manufacturing process for the pinion consisted of flame cutting the basic profile with an allowance for finishing. The fillets were then bored and the final profile was shaper cut. The pinion was then carburized, hardened and tempered. The actual hardness traverse from a tooth is shown in Figure 6.

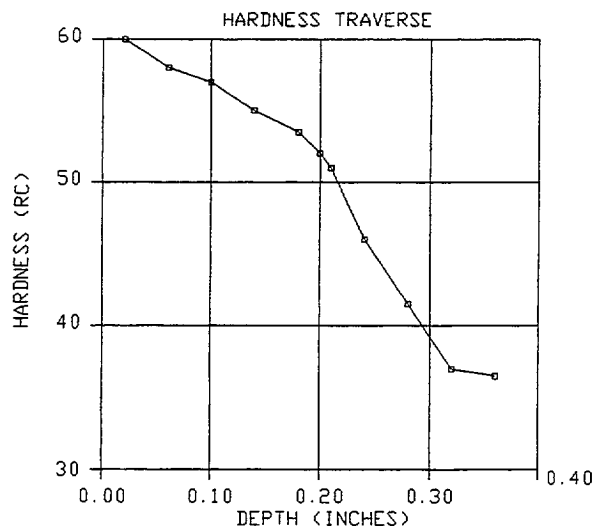


FIGURE 6

PINION LOADING, PREDICTED RATING AND STRESS ANALYSIS

At the maximum required holding load of 1,600,000 lbs. tangential, the AGMA 2001 [9] pinion bending stress was 145 KSI. With a life factor of 2.7 for less than 10^3 cycles, the predicted Service Factor (SF) is 1.21. The AGMA contact stress was 528 KSI. The calculated contact stress was not considered realistic because there was local yielding of the rack in the contact zone.

The pinion of the jack-up rig was analyzed using the "ANSYS" finite element program to calculate the principal stresses at the root of the tooth due to the normal force applied at the highest point of contact when meshing with the rack. Only one tooth and a portion of the adjacent tooth were modeled because of the minimal effects of the other pinion teeth, see Figure 7. The pinion was modeled using the STIF42 - 2D isoparametric solid elements from the ANSYS library. This element is used for two dimensional models of solid structures and can be used either as a biaxial plane element or an axisymmetric ring element. The element is defined by four nodal points and has two degrees of freedom at each node. A two dimensional model with a unit depth was considered adequate as there would be no out of plane effects in the pinion with it's 8.5 inch face width. Figure 8 presents the calculated principal stress at the root of the pinion tooth.