NEW DANJOINT HIGH PERFORMANCE OIL LUBRICATED GEAR SPINDLES FOR ESSAR STEEL ALGOMA'S DSPC *

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Abstract

Essar Algoma Steel, Canada, awarded Danieli Transimissions a strategic order for the upgrade of the main drive spindles belonging to the most loaded stands of the Hot Strip Mill, F1-F2, F5 and F6. Featuring special heavy duty design and advanced torque monitoring system, these spindles replace existing competitors' grease lubricated design with the efficient continuous oil lubricated solution to withstand the tough working conditions, increase life expectations and provide room for a product mix extension. The first couple of spindles have been installed in September 2017 by the expert Service team and are showing already good and reliable performance. Progressively all the others are being installed.

Keywords: Gear Spindles, Oil Lubrication, Drive Train, Hot Strip Mill, Torque Transmission, Crowned Gear, Finite Element.

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1 INTRODUCTION

The upgrading and modernization of rolling mills are playing a key role in improvement of a steel plant competitiveness in the actual market. Substantially the customer's requests are to expand the product mix with steel grades having high mechanical properties or to increase the plant profitability. The first is usually achieved by increasing the max transmitted torque; the second is achieved by a more reliable and a long-term design of machines.
The drive train represents a relevant issue in a rolling mill modernization project. Gear spindles are widely used in the drive trains of rolling mills for the steel making, aluminum making and non-ferrous alloy industry. Working conditions are extremely tough due to high alternating or pulsating rolling torques in the roughing stands and high torques and speeds in finishing stands. Overloads, temperatures and lubrication along with oxide and slag are also critical issues that contribute to create a severe working condition.
A new generation of gear spindles featuring continuous oil lubrication has been developed to deliver the constantly increasing rolling torques aimed to produce harder steel grades and to increase the life time of all critical components. The new series of DANJOINT oil lubricated gear spindles derives from extensive experience, know-how in drive train technology and on-site testing boasting a dramatic increase in fatigue life compared to the standard grease lubricated spindles.

2 ESSAR STEEL ALGOMA OVERVIEW

Essar Steel Algoma (formerly Algoma), a company of Essar Steel Holdings Ltd since 2007, produces hot and cold rolled sheet and plate through a fully integrated steel-making process with a raw steel production capacity of approximately 2.8 million tons per year.
The production of liquid steel is implemented using two 260-ton basic oxygen furnaces by combining molten iron with scrap steel and another required alloy. After the refining process through two metallurgy stations, the electric ladle and the chemical reheating ladle, the plates and coils are produced by means of three lines:

- The Direct Strip Production Complex (DSPC) comprising of a continuous thin slab caster coupled with direct hot strip mill.
- The 166” Plate Mill and the 106” Strip Mills.
- The Cold Mill Complex capable of pickling, reducing, annealing, tempering and slitting.

The DSPC, designed and supplied by Danieli in 1995, is capable to produce strip range of thickness and width respectively between 1.2 mm and 1.6 mm and between 810 mm and 1600 mm. The product mix includes grades such as commercial quality, drawing quality, peritectic, high strength low alloy (HSLA), high carbon grades and formable grades.

In a DSPC layout, the one stand non-reversing Roughing mill, coupled with one vertical Edger is linked to a twin strand Thin Slab Caster through two tunnel-type equalizing furnaces. Thus, the six stands finishing mill is directly connected to the Roughing Mill through a heated transfer table and the final strip is then conveyed through the strip cooling equipment for the final coiling via one or more down coilers.
Fed by a slab caster, the 166” Plate Mill and the 106” Strip Mills complete the broad range of products with sheet and light gauge plate to a maximum slit edge width of 2440 mm, carbon and HSLA plate up to 3860 mm wide.

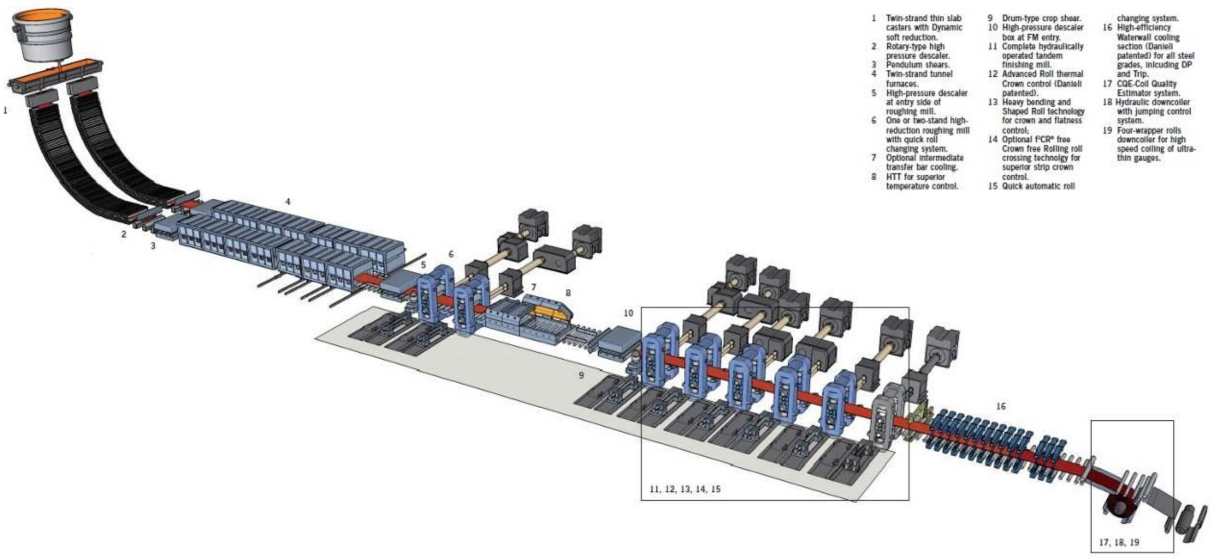

Figure 1. DSPC layout.

Figure 2. DSPC Finishing mill.

3 GEAR SPINDLES

Since the beginning the DSPC finishing mill was running with Danieli's Competitor grease lubricated gear spindle but, during the years, the spindle design has been reviewed by Danieli's Competitor without really solving the issues that Essar Algoma was facing so far. For this reason, in February 2014, Algoma, awarded Danieli Transmissions a strategic order for the upgrade of the main drive spindles belonging to the most loaded stands of the Hot Strip Mill, F1-F2, F5 and F6. Featuring special heavy-duty design and advanced torque monitoring system, Danieli spindles in fact, are replacing the existing grease lubricated design of the competitors with the efficient continuous oil lubricated solution to withstand the tough working conditions, increase life expectations and provide room for a product mix expansion. The first couple of spindles was installed in September 2017 by the expert Service team and are showing already good and reliable performance. All the others are being installed progressively.

3.1 F1/F2 issues

The installed spindle roll end outer diameter is 724 mm with an intermediate gear coupled with a spline connection to the roll hub and meshing with the male gear. The gear material is carburized, and the root is centered on the male hub gear (root piloting).

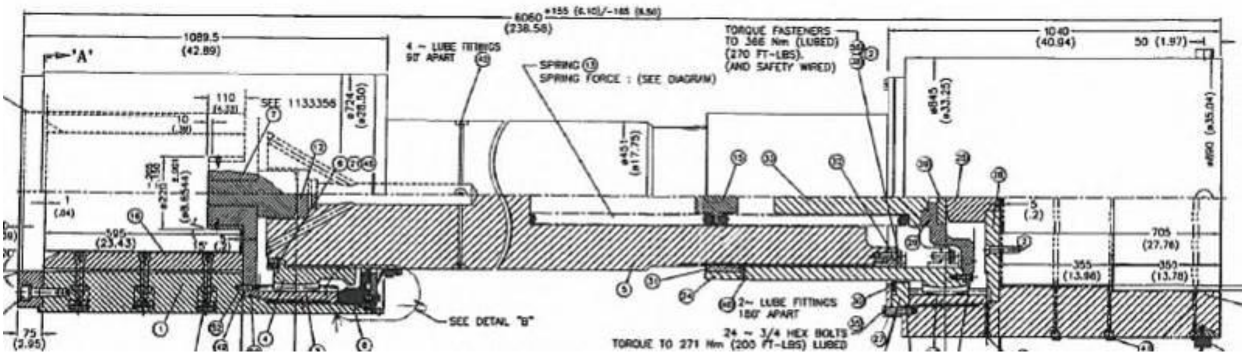

Figure 3. F1/F2 grease lubricated spindles.

The first important problem that these spindles have suffered since the start up is grease wash out from the roll end spindle assembly, probably due to the high deformations under load, which led to accelerated wear of the gearing components. Lubrication breakdown results in lack of the protective film between teeth and dramatical increase of wear rate as well as heat. Moreover, distortion resulting from carburizing, if not reduced by means of high precision machining and high misalignment can reduce considerably the number of teeth engaged under load and consequently increase the amount of stress on each tooth. All these factors may result in sub-surface shear and pitting/spalling of teeth.

Figure 4. Gear spindle teeth wear.

The intermediate gear teeth had static failures in the “3 and 9 o’clock” position. It is likely that the excessive misalignment of the spindle over the allowable limit during the roll insertion in the hub causes teeth cracking.

3.2 F5/F6 issues

The installed spindle roll end outer diameter is 600 mm with an intermediate gear, coupled with a spline connection to the roll hub sleeve, meshing with the male gear.

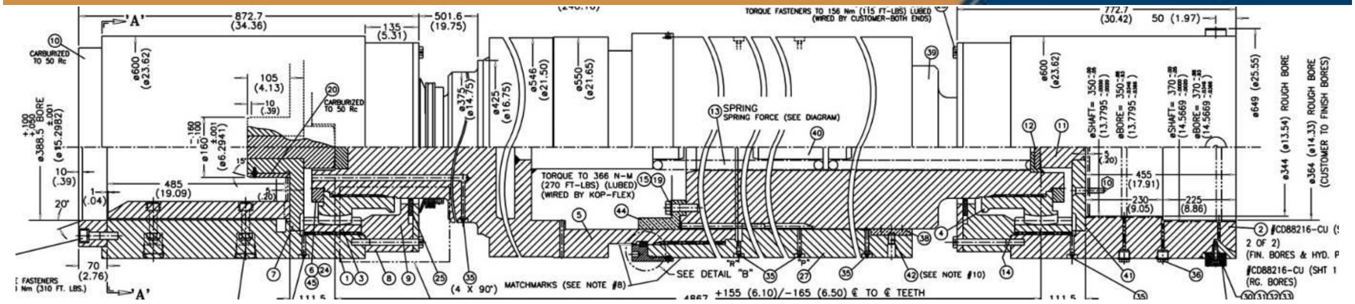

Figure 5. F5/F6 grease lubricated spindles.

This spindle generated interested due to failure of the bolts in the middle at the spline sleeve retaining ring. The changed design with threaded retaining ring failed as well. The root cause of the failure is expected to be the bending at the middle flex point generated by unexpected radial loads. The spline sleeve inner and outer pilots wear together with the inner bushing of the roll side thrust plate thus introducing eccentricity in the spindle shaft rotation. In addition to the spindle weight, the additional force created by eccentricity increases bending in the telescopic spline section with consequent failures.

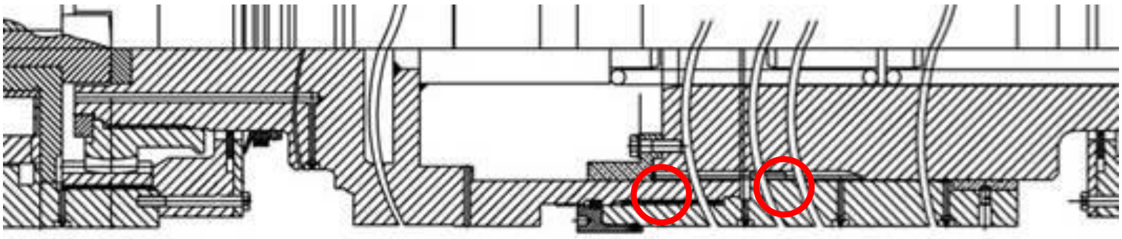

Figure 6. F5/F6 spline sleeve pilots.

4 NEW DANJOINT HP OIL LUBRICATED GEAR SPINDLES

Danieli Service designs and manufactures in their own facilities its DANJOINT HP Oil Lubricated Gear Spindles, for both Danieli and Competitor's hot and cold strip mills main drives. The technical advantages given by oil lubricated gear spindles are:

- Drastic reduction of damages typical of quenched and tempered gears with grease lubrication, like: pitting, abrasion wear, bonding and seizure.
- High efficiency in terms of power transmission.
- Low friction between contact surfaces.
- Increased lifetime of geared elements.
- Reduced energy consumption for spindle internal frictions.
- Very high spindle lubrication efficiency.
- Teeth working temperature always below 70°C.
- Constant cleanliness of the gears contact surface.
- Controlled cooling and oil viscosity.
- New sealing design with no risk for water infiltrations from work rolls into the oil circuit.

The oil lubricated gear spindles differ from the traditional grease lubricated ones by an internal oil lubrication circuit for forced and pressurized oil circulation with floating sealing and anti-rotation oil feed system. The spindles are provided with a rotary distributor fed by a lubrication system that can be a dedicated one or it can be a part of the plant main drives lubrication system. The oil flows inside the spindles, lubricates all mating parts and then it is discharged into an oil collecting box at the drive side. The oil then flows back to the lubrication unit main tank and then it is filtered, cooled and pumped back.

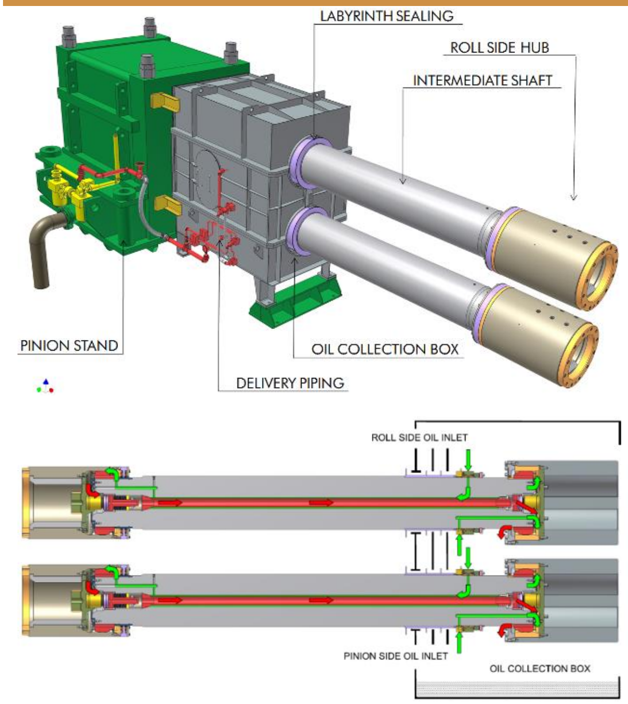

Figure 7. Oil lubrication circuit.

The material used for the gear components are tool steel, carburizing steel and nitriding steel, with in-house heat treatment.

Every design is conceived to meet the performance requested by each specific application, thus choosing the best combination of materials, heat treatment, tooth profile and crowning becomes of paramount importance, along with the high precision machining to give the desired tolerances.

Beside the above mentioned technical aspects, the oil lubricated gear spindles show off the following economical advantages:

> “Easy maintenance” design concept to reduce operation costs.
> Engineered to be quickly interchangeable and reduce downtimes.
> Intermediate geared sleeve to reduce costs of wearing components.
> Drastic reduction of lubricant consumption and relevant storage costs.
> No risk of human error during lubrication that may cause equipment failure.
> No need of lubrication maintenance personnel.
> No need to clean the area around the spindles from grease losses.

Compared to the grease lubricated gear spindles, the oil lubricated ones give the following environmental advantages:

> No more use of aggressive and extremely polluting greases with hydrocarbons and solid chemical additives.
> Limited environmental pollution.
> No grease released into atmosphere.
> No more presence of grease or flammable soaps in the spindle area.
> No more daily greasing maintenance procedure.

4.1 F1/F2 and F5/F6 DANJOINT designed for Essar Steel Algoma’s DSPC

The roll hub outer diameter for F1/F2 and F5/F6 spindles is 725 mm and 600 mm respectively. The gears are manufactured with precision ground carburized material and designed with a tip centering in the male hub crowned gear (tip piloting). The design, machining, materials and heat treatment are optimized to double the lifetime of critical components such as geared hubs. For critical applications, such as Essar Steel Algoma HSM, the shoot peening is performed to improve the fatigue strength of the tooth flank and root. In addition, the continuous oil lubrication contributes substantially to lifetime increasing by lowering the temperature in the gear mesh and removing all detrimental particles.

The telescopic concept is accommodated at the drive side with the middle shaft capable to shift back and forward.

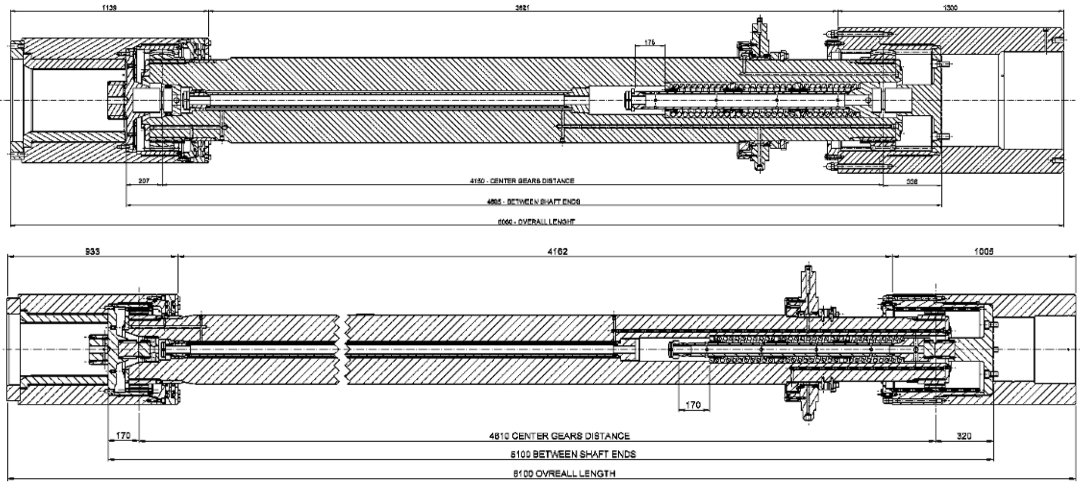

Figure 8. F1/F2 and F5/F6 HP DANJOINT oil lubricated spindles.

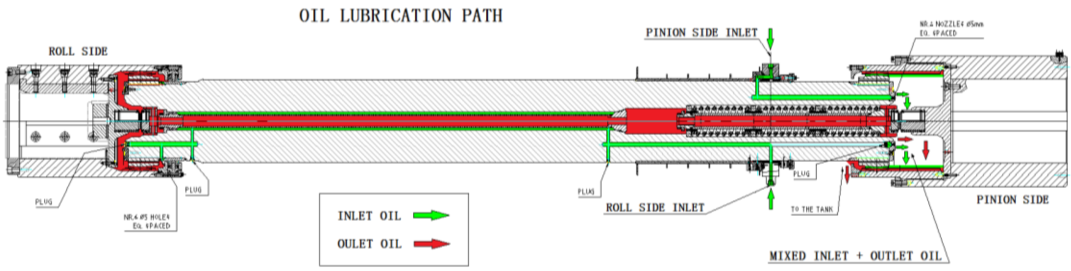

Figure 9. HP DANJOINT continuous oil lubrication path.

The gear components design optimization is performed step by step by means of analytical calculation according to existing bibliography, Finite Element Analysis and experience from previous designs.

The stresses generated in the gear meshing contact are analyzed by building up 3D Finite Element Model of the complete gear components. The model can simulate the non-linear contact between the teeth with a finer mesh in the contact area, thus obtaining a realistic stress distribution and deep understanding of the tooth profile behavior under load.

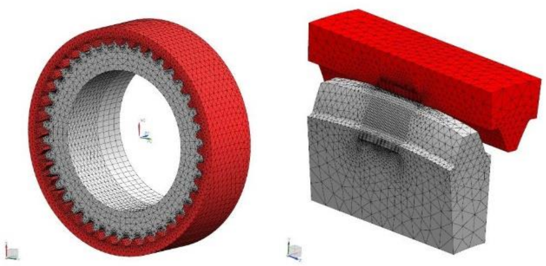

Figure 10. FEM.

The analysis was carried out at different misalignment angles from 0° to 2°. As the angle of misalignment increases, the number of teeth engaged under load decreases, as shown in the picture below, and consequently the peak surface stress increases.

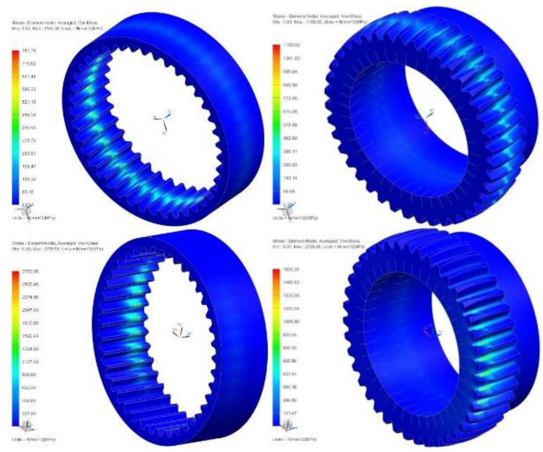

Figure 11. FEA stress results.

To detect also the stress distribution and the maximum stress value beneath the surface, the mesh is refined along the normal direction to the tooth flank.

4.2 Rolling Mills Feedback

The validation of gear spindle design features derives from tangible feedback of rolling mills in operation.
The oil lubricated gear spindles, installed on 7-stand finishing mill of a Danieli HSM, are exhibiting high performance in terms of reliability and gear components fatigue life. From stand F1 to F4 the roll end hub outer diameter is 725 mm without intermediate gear sleeve. The stands F5 to F7 have outer diameter of the roll end hub is 520 mm with intermediate gear sleeve. All the gears are manufactured with precision ground carburized steel with a tip centering in the male hub gear (tip piloting).
The HSM started in 2012 and after three years of rolling any critical component of the spindles was checked. The gear components were found in a good status with the typical polishing due to gears contact load without any pitting or spalling.

Figure 12. HSM Gear spindle components after 3 years of working.

A proof of the oil lubricated gear spindle achievable performances is also given by a Steckel Mill project with 535 mm and 475 mm roll end hub outer diameter and intermediate gear sleeve. The gears are manufactured with tool steel and carburized steel with a tip centering in the male hub gear (tip piloting). The mill has been rolling for two years and the gear components have a typical flank polishing. Compared to brand new crowned gear wheel, the ones that have been working for two years are not showing any damages.

Figure 13. Brand new gear spindle components for Steckel Mill.

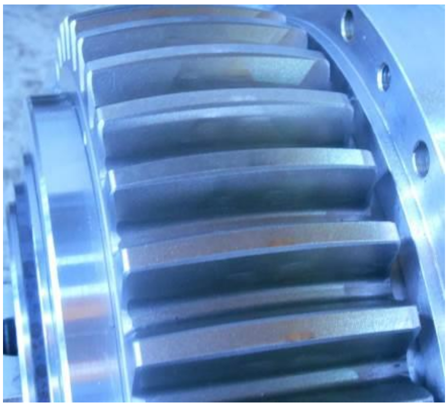

Figure 14. Steckel Mill gear spindle components after two years in operation.

In addition to technical and economical advantages, the replacement of grease lubricated gear spindles with oil lubricated ones avoids presence of grease and pollution in the spindle area. Moreover, the oil lubrication system (a collecting box, piping and instrumentation) can be adapted and integrated into the plant layout without any relevant modification, making it a smart and suitable design for revamps.

Figure 15. Before and after gear spindle replacement on HSM F7 finishing stand.

One of the latest gear spindle replacements was done on stands of HSM finishing mill. The previous grease lubricated gear spindles had the gear components, which had to be replaced every 6 months; instead the oil lubricated gear spindles have not experienced any failure or any part to be replaced after five years of operation.

5 SPINDLES INSTALLATION – ON SITE ACTIVITIES

The first set of spindles that were installed are the ones of the stand F5. The shut-down for the installation was planned from 22nd August 2017 to 24th August 2017.
Danieli team reached the plant on 18th August 2017. First phases were the check of the materials stored in the warehouse and the outline set-up of the torque monitoring system to minimize the activities during the shut-down. Drive side hubs were installed on available spare pinions in advance and were available for installation.

Figure 16. Torque Monitoring Off-line Set-up

The activities performed during the shut-down are the following:

1. Removal of the existing grease lubricated spindles;
2. Opening of the pinion stand and replacing of the geared parts with pre-assembled spares;

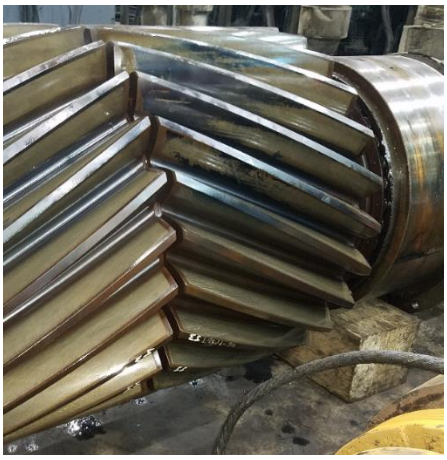

Figure 17. Existing Pinion Removal

3. Installation of the bottom frame of the oil tank and connection of the interconnecting piping between oil delivery placed beside the pinion stand and take over point of the oil lubrication system placed on the oil collecting box;

Figure 18. Bottom Frame and Piping

4. Installation of the spindles on the drive side hubs and bolts tightening to lock the intermediate gear and the drive side hub;

Figure 19. Spindles Ready for Installation

5. Installation of the anti-rotation arm that connects the top and bottom oil distributor installed on each spindle;

Figure 20. Spindles and Anti-rotation Device Installed

6. Mechanical checks of spindles and tank alignment;
7. Connection of the rotating distributors to the oil deliveries placed on the oil tank by means of 4 flexible hoses (one for each oil delivery: the roll side top, the roll side bottom, the drive side top, the drive side bottom);

Figure 21. Oil Lubrication Connection

8. Installation of the oil collecting box top covers and bellows to prevent oil leakage;
9. Set-up of the oil parameters in terms of pressure and flow for proper lubrication and test without spindle rotation;

Figure 22. Independent Oil Flow Regulation for Each Delivery

10. Electrical connection and configuration of the torque monitoring system installed on the spindles;

Figure 23. Electrical Connections

11. Work rolls insertion and movements test to check worst positions in terms of maximum and minimum opening and shifting strokes;
12. Cold test with monitoring of spindle oscillations during rotation, oil parameters and temperatures in different points, with different steps of speed, up to maximum one;

Figure 24. Oil Discharge Check

13. Hot test with monitoring of spindle oscillations during rotation, oil parameters and temperatures in different points during rolling, every 2 working hours.

Figure 25. Rotation Test

Figure 26. New Equipment During Rolling

6 DANEASY: DANIELI EARN ASSET SECURITY YEARLY – MAINTENANCE AS A DRIVER FOR PRODUCTION OPTIMIZATION

DANEASY makes preventive maintenance accurate fast and handy. Beside torque monitoring, DANEASY features a full spectrum of technologies and application to suit any drivetrain needs. The purpose is to monitor, analyze and predict in real time all necessary information coming from the site. Vibration, oil quality, noise and temperature sensors can be installed in specific positions to detect the actual value of these parameters. These values are then combined and analyzed together to understand in real time the equipment health condition so that a reliable prediction can be made. Drivetrains are safe and sound with DANEASY. The smart way to protect capital assets

7 TORQUE MONITORING SYSTEM

During rolling operation, the torque from the motors to the work rolls is transmitted through the spindles, these are the most loaded components of the entire drive chain, for this reason it is very important to monitor their condition and predict their life time. It is possible thanks to the Danieli torque monitoring system.

Main Design Assemblies:

> Static assembly

> Dynamic assembly

The static part includes (installed on the ground):

- Junction box with control units
- Inductive head

The dynamic part includes (installed on a spindle):

- Electronic components
- Strain gauges
- Mechanical supports

7.1 Operating process

The system, by means of a contactless measurement, records and transfers physical values from/to rotating components. The particularity of Essar Steel Algoma's System is the possibility to transmit the data also during the spindle shifting, this permits to monitor constantly the torque in all spindle working position.

7.2 Torque measurement

During rolling, the spindle shaft is deformed, the strain gauge applied on the shaft follows the spindle deformation, that is converted by an electronic control unit (System is set up based on a spindle shaft mechanical properties and a maximum admissible torque) in an analog output signal 4-20mA with the real time torque value readable from customer Automation plc.

8 RETURN OF INVESTMENT

The purpose of this document is to explain the financial benefits that would derive from the installation of DANJOINT HP Oil Lubricated Gear Spindles in Essar Steel Algoma's F1/F2 and F5/F6 finishing stands only (these being in addition to the significant health, safety and environmental benefits that would result).

The results of the high efficiency oil lubricated gear spindles will be presented in terms of:

1) Power supply cost savings;
2) Spares and maintenance cost savings.

8.1 Power Supply Cost Savings

The analysis was carried out estimating the total energy loss [kWh] that would derive from the installation of the DANJOINT HP Oil Lubricated Gear Spindles compared to the grease lubrication one.
The higher efficiency of the oil lubricated gear spindles makes it possible to achieve an electricity cost saving of more than 500,000.00 USD in a 10 (Ten) years span per each stand. Considering all 4 (four) Essar Steel Algoma's stands equipped with DANJOINT HP Oil Lubricated Gear Spindles, the total saving in 10 (ten) years will be more than 2 MNL USD.

The following table summarizes all input data and calculations (cost of energy per kWh was taken as an average Electricity price in Canada).

Table 1. Net saving in 10 years for 1 stand

Main drive motor electricity consumption for 1 stand	
Nominal power (kW)	7,000
Average factor	100%
Average power (kW)	7,000
Working days per year	335
Working hours per day	24
Total working hours per year	8,040
Rolling time percentage	60%
Effective rolling hours	4,824
Effective electric energy consumption (kWh)	33,768,000
Efficiency grease lubricated spindle	98.6%
Loss percentage grease lubricated spindle	1.40%
Energy loss with grease lubricated spindles (kWh)	472,752
Efficiency oil lubricated spindle	99.3%
Loss percentage oil lubricated spindle	0.70%
Loss difference between grease and oil lubricated spindles	236,376
Electricity cost per kwh (USD)	0.110
Saving per year (USD)	**52,002.72**
Total saving in 10 years (USD)	**520,027.20**
Lubrication unit electricity consuption for 1 stand	
Oil flow per spindle (lpm)	40
Number of spindles	2
Total oil flow (lpm)	80
Feeding pressure (bar)	6
Hydraulic power (kW)	0.80
Pump efficiency	70%
Electric power (kW)	1.14
Total working hours per year	8,040
Total energy loss for oil circulation for 1 year (kWh)	9,189
Cost per year (USD)	1,011
Final net saving in 10 years for 1 stand (USD)	509,919.77

8.2 Spares and Maintenance Cost Saving

The cost saving related to spares and maintenance was calculated considering the average of the direct costs due to spares, manpower and lubricant consumption.
Potential induced costs due to mill downtime are not considered.

The chart below summarizes a comparison between purchasing and maintenance costs for new DANJOINT HP Oil Lubricated Gear Spindles and maintenance costs for existing grease lubricated gear spindle. The investment in the new oil lubricated gear spindles is completely paid back just after 2 years and in a 10 (ten) year time span the investment generates more than 500,000.00 USD for each stand, more than 2 MLD USD for 4 (four) stands.

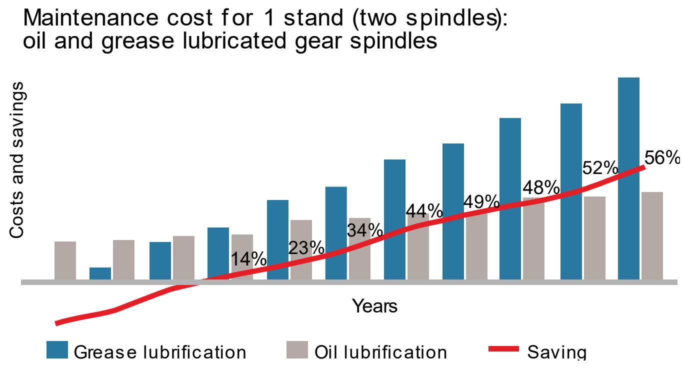

Figure 28. Maintenance cost for 1 stand (two spindles): oil and grease lubricated gear spindles

8.3 Total Net Saving

As a conclusion the total net saving considering the electricity and the maintenance costs will be.

	Electricity saving (USD)	Maintenance saving (USD)	Total net saving (USD)
Nr.1 (one) stand	509,000.00	515,273.00	1,024,273.00
Nr.4 (four) stands	2,036,000.00	2,061,092.00	**4,097,092.00**

9 DAN CORP SERVICE CENTRE

In conjunction with the successful intervention on site for oil conversion of spindles in stand F1-F2-F5-F6, Danieli

made the decision to open its own Service Centre in the USA. The aim of the company is to provide our customers with the best services in terms of repair, refurbishment and overhaul of Danieli equipment by installing original OEM parts and applying unparalleled knowledge about the equipment and its operation.
The new Service Centre located in Coraopolis, PA, will provide OEM quality repairs, parts and services, which our customers previously didn't have access to in the USA.
The area is operational by September 2018. It was designed to repair and service the majority of Danieli equipment installed in customer plants that are worn, in need of minor repair, have damaged parts, or need a complete overhaul. This equipment includes:

> Gearboxes and spindles;
> Shears and straighteners;
> Caster oscillators;
> Mill Mandrels;
> Levelers.

Finally, the new Service Centre will have an entire area dedicated to the training in both maintenance and operation practices.

Main skills of the DANIELI CORPORATION SERVICE CENTER:
Site area: **6 acres**
Service centre buildings: **55.000 sqft**
Office and training area: **6.000 sqft**
Crane capacity: **1x35 T + 2x20 T + 1x10 T**

10 CONCLUSIONS

Customers' continuous demands of reliable rolling mills drive train together with extremely tough working condition made the gear spindle design more challenging over the years. The design complexity relies on the selection of materials, heat treatment and tooth shape, but the right combination of those parameters is a consequence of know-how, experience and on-site testing.
The feedback deriving from on-site installation tips the scale in favor of oil lubricated gear spindles and the years of operation of the currently installed oil lubricated gear spindles flatly ascertain their advantages and performances over the grease lubricated ones. The fatigue life of a gear components can be remarkably increased because of the benefits introduced by oil lubrication such as heat removal and gears contact area cleanliness.

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