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A REFINED METHOD TO CHECK TOOTH CONTACT PATTERNS OF GEARS GUARANTEES FACTORY QUALITY TOOTH CONTACT, BUT WITH LESS EFFORT AND LESS RISK

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ABSTRACT

It is very important for gears to have the load distributed evenly over the face width during operation at the rated conditions. If the load is not distributed evenly over the face width, contact pressure and bending stress will increase locally, resulting in an increased risk of damage. To achieve an even load distribution, high precision is needed in designing, manufacturing, assembly and installation of gear units. The design, manufacture and assembly of the gear units are the responsibility of the gear vendor. These elements are checked, tested and inspected at the vendor's shop. The final check of the load distribution is in general the blue ink check of the tooth load pattern.

Proper installation in the field is the final step in ensuring acceptability of the gear tooth contact. It is essential to ensure that the casing does not get distorted during installation on the baseplate. The consequence of a casing distortion would be bad tooth contact, an uneven load distribution, resulting in local overload on the teeth and increased risk of gear damage leading to tooth failure. Typically, another blue ink check is performed on site as a final check of the load distribution of the tooth load pattern.

One method to ensure a proper installation of the gear unit without distortion of the casing is the so called "soft foot check". With this method, there are dial gauges placed on the four corners of the gear casing to check for casing movement. Soft foot is indicated when the casing deflects in vertical direction during releasing and tightening of the anchor bolts. Permitting the corner of the casing to deflect will lead to casing distortion and uneven tooth face contact. In such a case, shims are placed below the casing to eliminate the vertical deflection, i.e. avoid distortion of the casing.

This paper describes an advanced method to check whether a gear unit is installed properly, free of casing distortion. The method is based on using a precision spirit level on two reference supports attached to the casing of the gear unit (see Figure **7** and Figure 8). When the gear unit is installed and its anchor bolts are tightened, the two readings taken with the precision spirit level have to be compared. The difference between the two readings indicates a mislead angle and has to be within a defined tolerance. Previous to that, the gear manufacturer has checked the tooth contact pattern in his factory while the casing was not distorted. Achieving the same alignment on site makes sure that the tooth contact pattern is equivalent to the manufacturing condition.

The method has been used for many years on gear units. The check is reliable: if the spirit level readings are within tolerance, the tooth contact is within tolerance too. No blue ink test is required. The gear unit does not have to be opened, not even its inspection cover. No anchor bolts need to be released and tightened during the measurement, as with the soft foot check. Thus, the time needed to check the tooth contact is strongly reduced. The check can be performed within regular time intervals by the operating staff within minutes as opposed to the soft foot check, which requires 3 to 4 hours and staff with special training. No special tools are required to perform the check, only a small wrench and a precision frame spirit level are needed; both are commodity tools. In total, the quality of installation and maintenance is improved while at the same time work can be done faster.

LOAD DISTRIBUTION IN THE GEAR MESH

Ideally the load is distributed evenly over the face width of a gear, while it is operating at rated load. An even load distribution is given if the tooth flanks of two meshing gears are in contact over the whole face width. This ideal condition could be achieved if the two gear shafts would be perfectly parallel and if the shafts and teeth would not deflect, not bend and not distort during operation. In reality, mechanical and thermal loads do cause deflections and distortions of the gears and the tooth flanks deviate from the theoretical ideal helix form (see Figure 1). In order to get an even load distribution, the gears are manufactured with a lead modification (helix modification). The lead modification is an intentional deviation of the pinion and/or the gear wheel tooth flank from the theoretical helix form. By applying the lead modification, typically on one of the two mating gears, the deflections that are experienced during operation are compensated for.

As a result of the lead modification, the load will be distributed evenly during operation with rated load. When operating at low loads or at no load, the load distribution will not be even.

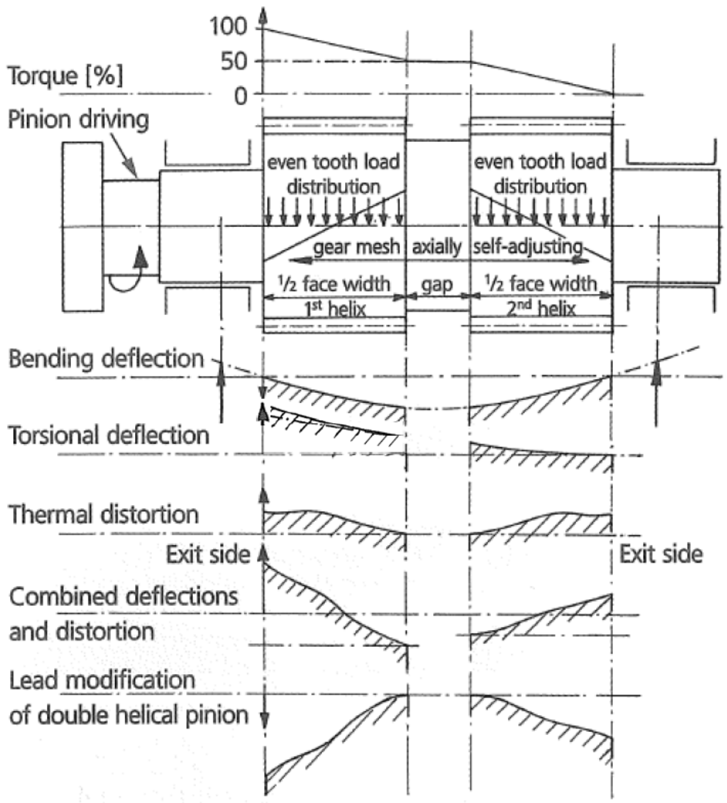


Figure 1. Factors influencing the tooth load distribution [1]

When rating the gears, the load distribution is taken into account by a factor called "Face Load Distribution Factor K_H" (see Figure 2 and Equation 1). When the load is evenly distributed over the face width, the value of the factor is equal to one: K_H =1.0 (see left side of Figure 2). A value of K_H =1.5 represents a case with uneven load distribution, where the maximum specific load on the tooth flank is 1.5 times the mean specific load (see right side of Figure 2).

$$K_H = \frac{maximum\ specific\ load}{mean\ specific\ load} = \frac{\frac{F_t}{b}max}{\frac{F_t}{b}m} \qquad (1)$$

K_H=1.0 K_H=1.5

Figure 2. Face Load Distribution Factor K_H

The face load distribution factor reduces the allowable power for a gear according to Equations 2a and 2b.

$$\mathbf{P_{az}} = \frac{1}{K_H}\left(\frac{\left(\frac{\pi * n_1}{60}\right) * b}{10^6}\right)\left(\frac{Z_I}{K_v C_{SF}}\right)\left(\frac{d_{w1} * \sigma_{HP} * Z_N}{Z_E}\right)^2 \qquad (2a)$$

$$\mathbf{P_{ay}} = \frac{1}{K_H}\left(\frac{\left(\frac{\pi * n_1}{60}\right) * b}{10^6}\right)\left(\frac{d_{w1} * m_t * Y_J * Y_L * \sigma_{FP} * Y_N}{K_V * K_{SF}}\right) \qquad (2b)$$

where:

P_{az} = allowable transmitted power in terms of pitting rating
P_{ay} = allowable transmitted power in terms of bending strength rating
K_H = Face Load Distribution Factor
n_1 = pinion speed, rpm
b = net active face width, mm
d_{w1} = operating pitch diameter of pinion
Z_E = elastic coefficient
Z_I = geometry factor
Z_N = contact stress cycle factor
K_v = dynamic factor
K_H = Load Distribution Factor
C_{SF} = service factor for pitting rating
K_{SF} = service factor for bending strength rating
σ_{HP} = allowable contact stress number;
σ_{FP} = allowable bending stress number
m_t = transverse module, mm
Y_J = geometry factor
Y_N = bending stress cycle factor
Y_L = reverse loading factor

BLUE INK CHECK

The Blue Ink Check is a traditional way of checking the load distribution over the face width of gears by checking the contact between the teeth of two mating gears. Today's technology allows checking the geometry of tooth flanks with a very high accuracy by means of 3D Coordinate Measuring Machines specifically designed and built for checking gears. Knowing the tooth flank geometry of two mating gears allows predicting the tooth contact. Nevertheless, it is still common to check the tooth contact of two mating gears by means of the blue ink check. The three main reasons to still use this method are: one, it is easy to understand, two, it allows to directly check the pair of mating gears and three, it can be used when the gears are installed in the casing and the gear unit installed in the final position in the machine. Thus, the influence of additional factors that can change the load distribution (e.g. casing distortion due to external loads, see next section) are taken into account.

The Blue Ink Check is also called "soft blue contact check" or "soft lacquer contact check". It is accomplished by coating the flanks of three to five teeth on one of the mating gears with a thin layer of a soft lacquer, then rotate the gear such way that the coated teeth pass through the gear mesh and transfer lacquer to the teeth of the other gear, and finally inspect and make a record of the tooth flanks with the transferred lacquer. In the past, the most common lacquer used for this check had a blue color, thus giving the name "blue ink check".

Ideally, the check should be performed through the inspection cover, with the upper casing part mounted. That way a potential influence of the tightening forces of the bolts in the casing split line and of the stiffness of the casing upper part would be taken into account. In reality, this will not be possible many times; in those cases, the check has to be performed with the upper part of the casing removed.

The procedure for the blue ink check is:

- Thoroughly clean the teeth of both gears
- Coat the load flanks of three to five teeth with a soft lacquer. It is essential for this check to apply a very thin layer of soft lacquer with constant thickness; a layer too thick or variable thickness of the layer will provide incorrect reading.
- Rotate the coated teeth through the mesh, so the lacquer is transferred to the tooth flank of the other, uncoated gear. It is recommended to turn the pinion by hand while applying a light load to the bull gear shaft by hand or with a brake.
- Inspect the teeth with the transferred lacquer.
- Apply transparent tape on the tooth flanks with transferred lacquer, lift the tape from the teeth and apply it on a white sheet of paper; this will provide a record of the tooth contact patterns.

The gear manufacturer will calculate in advance the amount of lead modification for each gear and the predicted tooth contact pattern. An example of a specific gear unit is shown in the top part of Figure **3**. A tape lift of the recorded tooth contact pattern is shown in the bottom part of Figure **3**. The recorded pattern matches well with the predicted one.

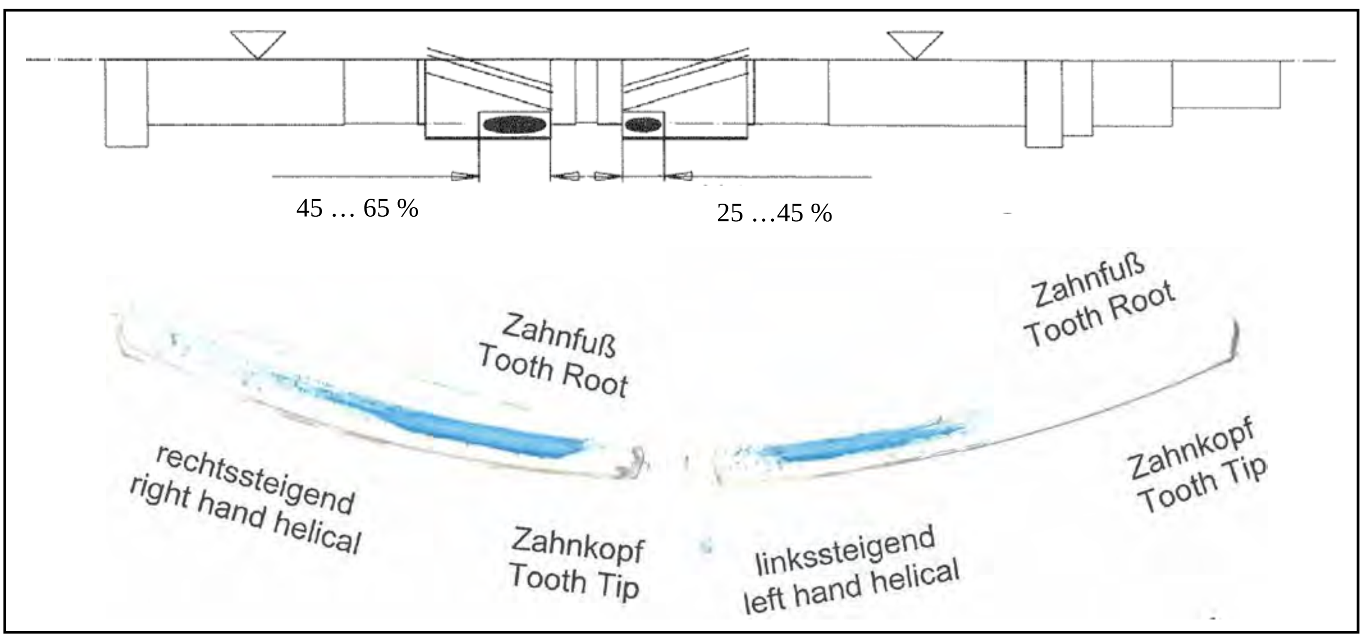


Figure 3. Tooth load contact pattern, predicted and tape lift recorded

CASING DISTORTION AND ITS INFLUENCE ON LOAD DISTRIBUTION

Under ideal circumstances, the gear shafts are parallel to each other and the load distribution will be uniformly distributed in the gear mesh, when the unit is running at rated condition. This is shown schematically in Figure 4.

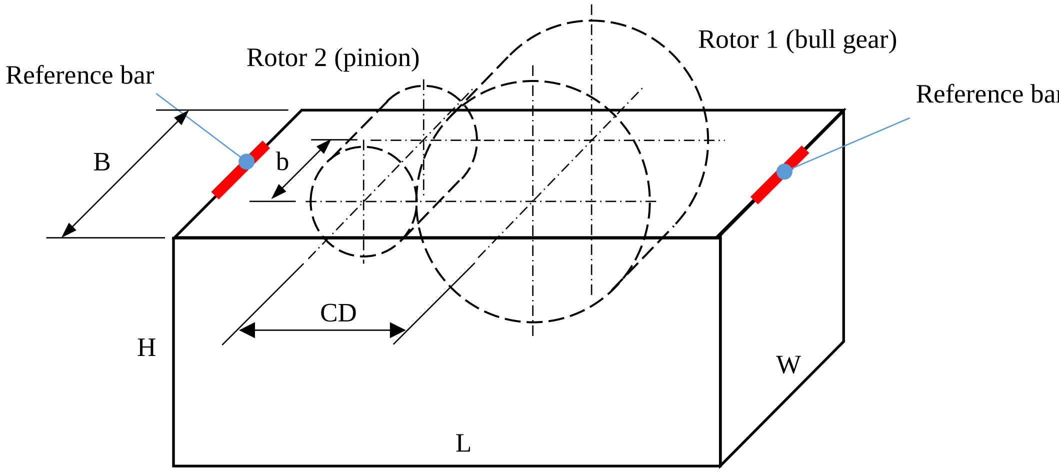


Figure 4. Schematic of a gear set in a casing lower part

b:	gear face width in mm
B:	bearing span in mm
CD:	center distance in mm
H:	Casing height in mm
L:	distance between the reference bars (length of the casing) in mm
W:	Casing width in mm

In reality, when a gear unit is set in place on its base, frame, or sole plate, one or more of the 'feet' are not making good contact with the base, frame or sole plate. Due to that, the casing can be distorted (twisted). As a consequence, the gear shafts will not be parallel to each other and the load not distributed evenly in the gear mesh.

Figure 5 gives a closer look at the split line plane of the gear unit. Assuming one corner of the casing is lifted upwards due to bad contact between casing and baseplate, the casing would be twisted. One reference bar would remain levelled, while the other one would be inclined by an angle "α0".

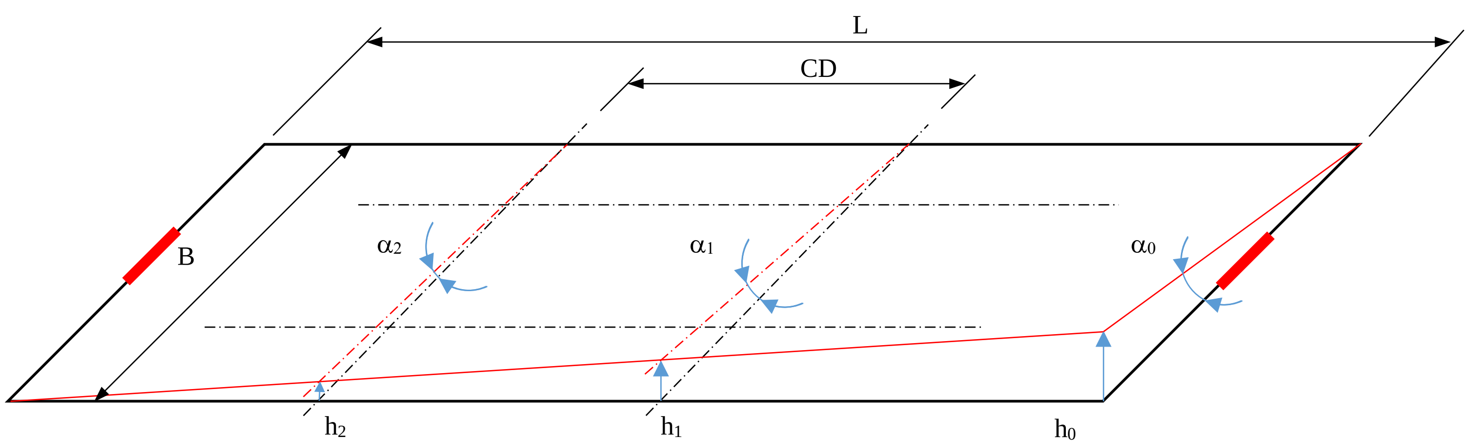


Figure 5. Schematic of the gear casing split line plane (undistorted vs. distorted)

Both rotors would be out of level too, rotor 1 by an angle called α_1 and rotor 2 by an angle called α_2. The differences in height ("h_0" in the corner of the casing, "h_1" on rotor 1 and "h_2" on rotor 2) have small values in reality. Accordingly, the deflections on the casing are small and the deformations can be assumed to be linear and elastic.
In reality, both reference bars can be out of level. In such a case, the difference between the two angles measured on the two reference bars can be considered to be the angle α_0. All the following considerations and equations remain valid.
For determining the deviation in the tooth contact, the difference $\Delta\alpha$ between the angles α_2 and α_1 has to be known. This can be calculated, if the dimensions L (distance between reference bars, equal to casing length), B (bearing span) and the angle α_0 (angular deviation between the two level readings on the reference bars) are known.
The relation between the angle values of "α_i" and the height difference values of "h_i" is given by Equation 3.

$$\alpha_i = \frac{h_i}{B} \qquad (3)$$

where
α_i: one of the angles α_0, α_1 and α_2 in radian
h_i: one of the height difference values h_0, h_1 and h_2 in mm
B: bearing span width in mm

The angular difference $\Delta\alpha$ can be calculated

$$\Delta\alpha = \alpha_2 - \alpha_1 = \frac{h_2}{B} - \frac{h_1}{B} = \frac{h_2 - h_1}{B} \qquad (4)$$

By using the geometrical rules of similarity in the geometry shown in Figure 5, one can deduct Equation 5.

$$\frac{h_0}{L} = \frac{h_2 - h_1}{CD} \qquad (5)$$

Combining equations 3, 4 and 5 results in the equation for the angular deviation $\Delta\alpha = \alpha2-\alpha1$.

$$\Delta\alpha = \alpha_0 * \frac{CD}{L} \qquad (6)$$

With the value of $\Delta\alpha$ known, the gear manufacturer can calculate the influence on the load distribution (i.e. a value for the load distribution factor K_H) and the allowable load for the gears. On the other hand, if starting from a given value for K_H, the equation allows to calculate an allowable deviation angle α_0 that has to be taken as a limit during the installation of the gear unit.

SOFT FOOT CHECK

"Soft foot" generally describes any condition where poor or no surface contact is made between the underside of the casing feet and where they contact the base plate or frame. This problem is often compared to the problem of a short leg of a four-legged chair. That comparison can help to quickly understand the basic issue; nevertheless, in reality, the soft foot is a more complex problem. The consequence of a "soft foot" is that the gear unit casing is distorted, when the anchor bolts are tightened, and due to that, the tooth contact may be compromised.
A detailed description of soft foot can be found in Piotrowski's "Shaft Alignment Handbook" [2]. Piotrowski also describes a couple of procedures to check machinery equipment for soft foot. One of the procedures is described below in short:

1. Tighten all of the foot bolts holding the machine in place.
2. Place one dial indicator at each bolt location holding the gear unit casing in place. Anchor the dial indicators to the frame or base and place the dial indicator stems as close as possible to the bolt-holes; insure that the stems are touching the top of the feet, and zero the indicators at mid-range.
3. Loosen one of the anchor bolts and watch all indicators for movement (see Figure 6). Take notes for the movement of every indicator. Leave the bolt loose.
4. Loosen the other anchor bolts one by one. Take notes for the movement of every indicator, after the loosening of every bolt. Leave the bolts loose.
5. Once all of the bolts have been loosened, review what you observed when each bolt was loosened. If only one indicator

showed more than 2–3 mils of movement, then there is probably a soft foot condition at that foot only. If more than 2–3 mils of movement were noticed at several bolt locations, then there is probably a soft foot condition at each one of those feet.

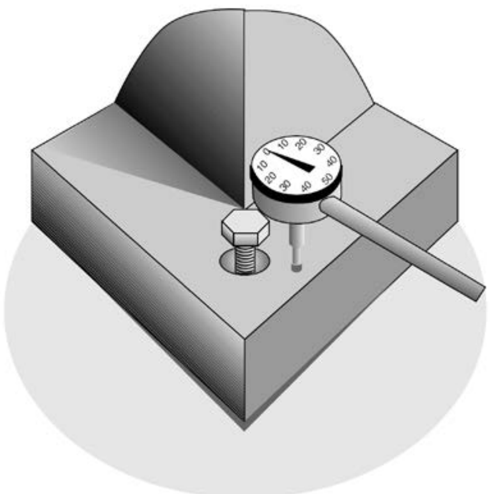
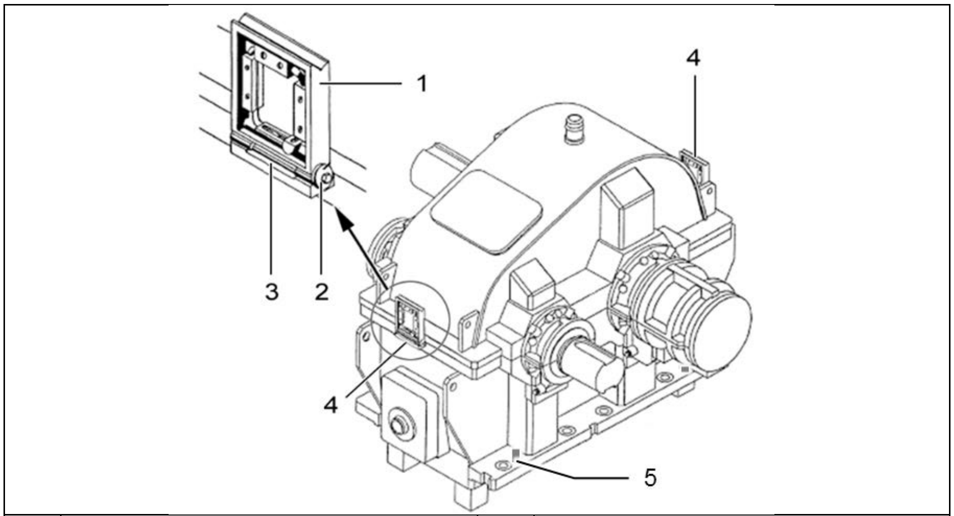


Figure 6. Soft foot check – step 3

CASING LEVELING CHECK

The basic idea of this method is to ensure that the casing of the gear unit is not distorted, when the gear unit is installed and its anchor bolts tightened. Previous to that, the gear manufacturer would check the tooth contact pattern in his factory while the casing was not distorted. Achieving the same alignment on site makes sure that the tooth contact pattern is equivalent to the manufacturing condition. This is simply ensured by comparing the readings taken with a spirit level on both sides of the gear and the difference remaining within a defined tolerance (see Figure 7).



1	Precision shaft spirit level	4	Two supports with reference bars
2	Washer	5	Jacking bolts (4x) for casing alignment
3	Reference bar		

Figure 7. Reference bar and spirit level on a gear unit, schematic

The lower casing part of the gear unit has two reference bars (see Figure 7 and Figure 8). These bars are precision cylinders with a diameter of 25 mm and a length of 160 mm. They are positioned on the two sides of the gear unit parallel to the gear shaft axes. Each bar has a washer mounted on one end. A precision shaft spirit level has to be positioned on the bar, with the flat side pushed to contact with the washer (see Figure 1 and Figure 2D).

Figure 8, A to F shows how to proceed for the check of the gear casing leveling.

1. Use a wrench to remove the cover plates that protect the two reference bars (see Figure 8A). Screw the cover plates to the same spot on the casing, but rotated upside down (see Figure 8 B and C). Remove anti-corrosive agent and clean the reference bars.
2. Apply temporary tags on the casing and on the cover plates indicating the location of the reference bar and orientation of the gear within the unit respectively. In the example shown in Figure 8 B and C the following terms and abbreviations were used:
    - “HS side”: high speed side
    - “LS side”: low speed side
    - “In” and “Input”: input side (the side where the driver is located)
    - “Out” and “Output”: output side (the side where the driven equipment is located)
3. Place the shaft level on one reference bar and check the level (see Figure 8 D and E). Make sure the flat side of the shaft level is pushed to contact with the washer. Take a picture or make a sketch of the level. Make sure that the tags are visible on the picture or that the sketch also indicates the location (HS or LS side) and the orientation (input and output side).
4. Place the shaft level on the other reference bar and check the level. Make sure the flat side of the shaft level is pushed to contact with the washer. Take a picture (see Figure 8 F) or make a sketch of the level. Make sure that the tags are visible on the picture or that the sketch contains information about the location (HS or LS side) and the orientation (input and output side).
5. Compare the two level readings. The difference between the two readings indicates the distortion of the gear casing, and thus a potential mislead in the tooth contact. That difference has to be within the tolerance specified by the gear unit vendor.

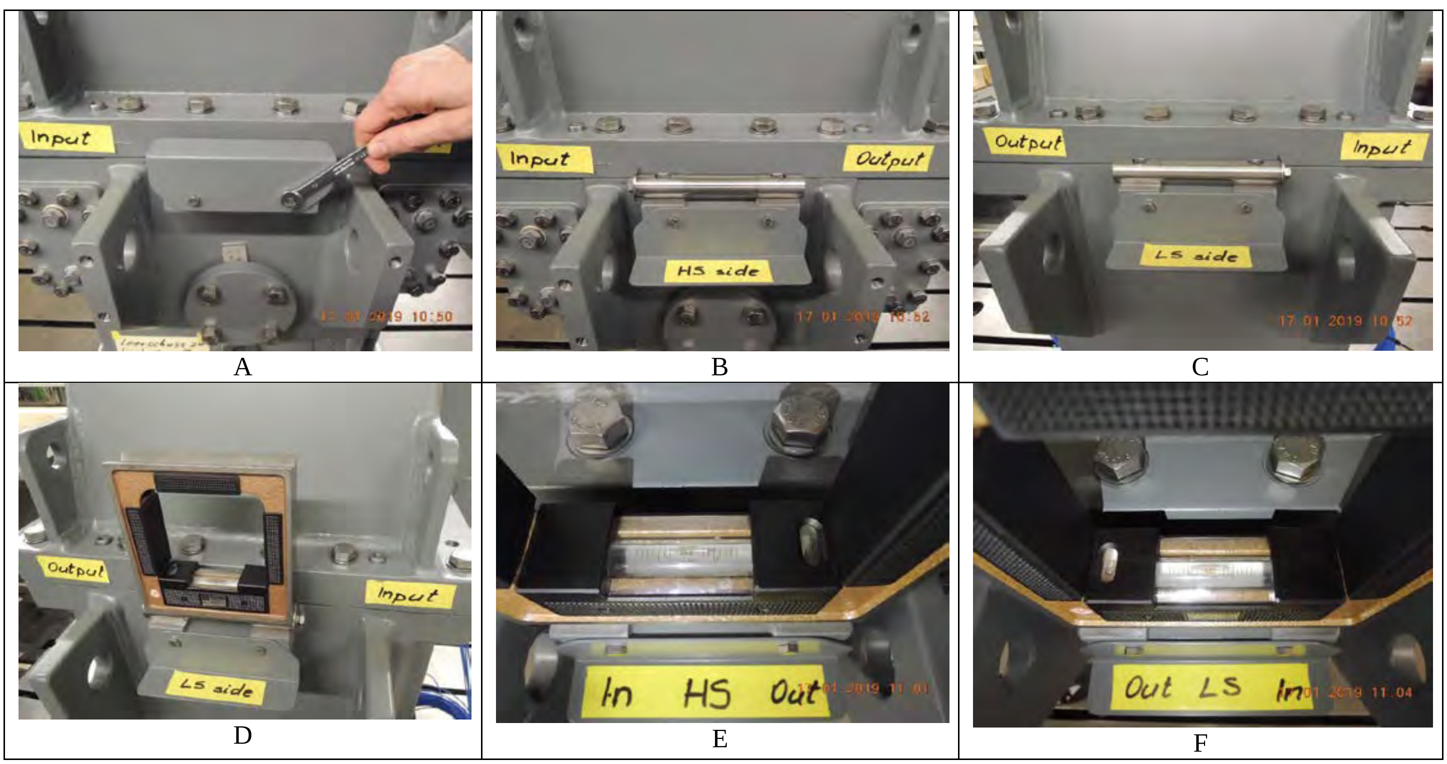
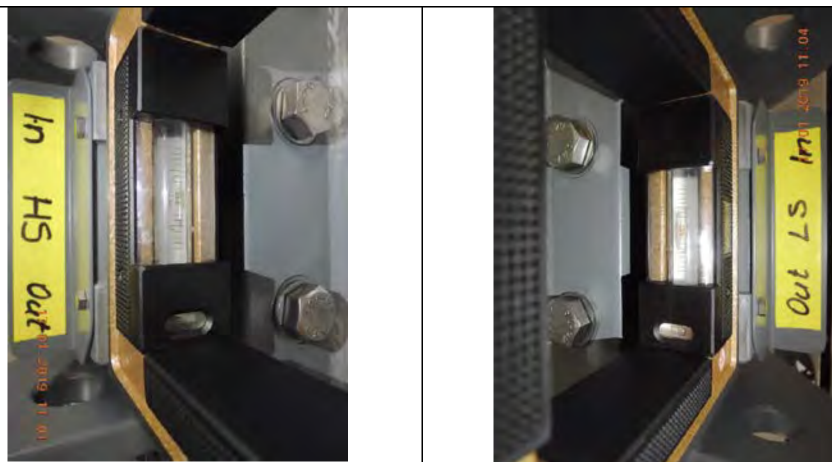


Figure 8. Checking the leveling of the gear casing

The following conditions have to be fulfilled when performing the check with the precision shaft level:

- The length of one side of the shaft level has to be at least 150 mm.
- The reference bars for the spirit level have to be clean.
- The spirit level has to be clean, especially the faces of the V-shaped groove which are placed on the reference bar.
- The spirit level has to have the same orientation when placed on each of the two reference bars, for example the flat face towards input side.
  Note:
  The gear vendor supplies the reference bar with the washer oriented towards the same side, in this example towards input side. By placing the shaft level with the flat face pushed to contact the washer, the shaft level has the same orientation on each of the reference bars.

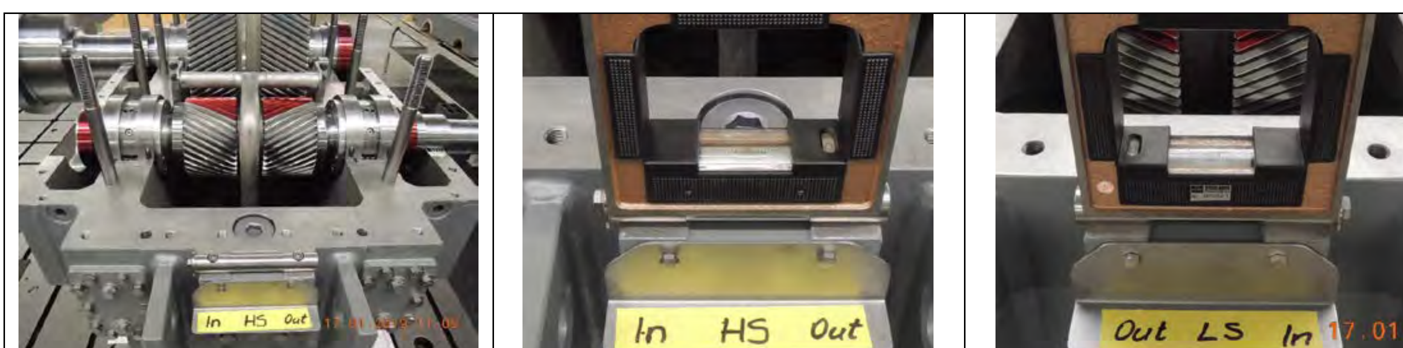
See Figure 8D for correct placement of the spirit level on the support.
When making a record of the level readings, it is practical to rotate the pictures taken of the levels in such way that input and output side are oriented in the same direction on both pictures – see Figure 9.



HS side | LS side

Figure 9. Pictures of level check rotated

The gear unit manufacturer performs the same level check two times during manufacturing. The first check is done together with the tooth contact pattern, while the casing is open (with the top of the casing removed, see Figure 10). A second check is done when the casing is closed (top casing part installed and all bolts in the casing split line tightened. For both checks, the difference between the two readings taken at the two reference bars has to be within the specified tolerance. This proves the casing is not distorted by tightening the bolts in the split line. It ensures that a level check performed on the gear unit on site, with the casing assembled and the bolts tightened, is representative for the tooth contact condition. On site, it will be sufficient to perform the check on the gear unit without opening the casing. This can be done whenever access is permitted to the unit, during operation as well as during stand still.



A | B | C

Figure 10. Level check with open casing (during manufacturing)

DESIGN DETAILS FOR THE REFERENCE BARS

The reference bars are made of stainless steel and manufactured according to the drawing in Appendix A. On fabricated casings, the supports on which the reference bars are mounted are made of carbon steel, pre-manufactured according to the drawing in Appendix B, welded to the casing and eventually their upper face (on which the reference bar are mounted) manufactured together with the casing. On cast casings, the supports can be integral with the casing. Manufacturing of the upper face of the supports has to be done with high precision, making sure that the faces are parallel to the plane determined by the axis of rotation of the two rotors.
It is practical to place the supports at the upper edge of the lower casing. Thus, the upper face of the supports can be manufactured together with the upper face of the casing lower part. That face will become the split plane of the casing and has to be manufactured with high precision anyway. Nevertheless, the supports do not have to be placed in the plane determined by the axis of rotation of the gear rotors. They can be attached to the lower casing part in other places too, as long as their upper face is parallel to both axes of rotation of the gear rotors.

CASE STUDIES

Three cases will be presented to demonstrate the effectiveness and the reliability of the method.

1. Case A: Casing alignment OK and tooth contact check OK
2. Case B: String test with a gear casing misaligned within tolerance.
   Shortly before the start of a string test with part load, it was detected that the gear casing was not properly aligned. The spirit level measurements were used to conduct an analysis of the resulting gear tooth lead mismatch and of the stress concentration on the teeth. Results revealed that the stress concentration was still acceptable and permission was given to run the part load test. After the test, the gear tooth flanks were inspected visually and found in perfect condition.
3. Case C: An Integrally Geared Compressor was overhauled after a failure in one compressor stage and in the gear unit.
   After the repair of the unit, an alignment check with the frame spirit level indicated a strong distortion of the casing. A blue ink check confirmed that tooth contact was not good. Shims were placed below one corner of the casing. Thus, the alignment of the casing and tooth contact and load distribution were corrected. The unit was put into operation. It has been operating successfully for 13 years.

CASE A: CASING ALIGNMENT OK AND CONTACT CHECK OK

A spare gear set was delivered for a gear unit installed between a gas turbine and a generator. A blue ink check was performed in the shop of the gear manufacturer in a checking stand with precision support rolls. The tooth contact was found to be in accordance with the design request. The result of this contact check is shown in Figure 11.

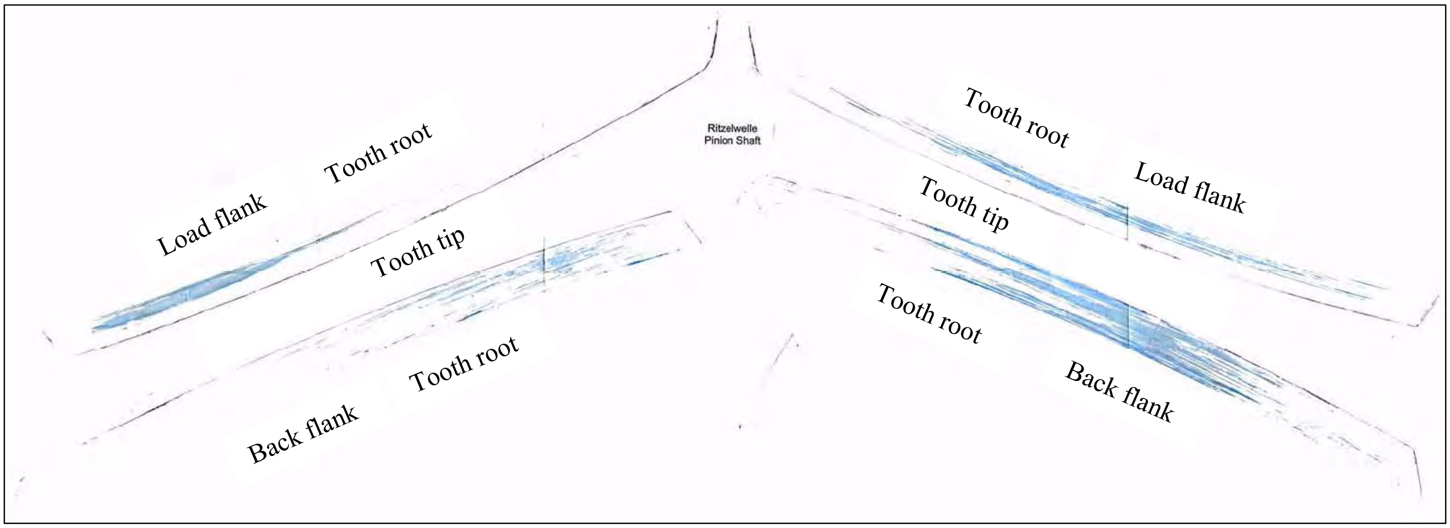


Figure 11. Result of the tooth contact check (blue ink check) at the gear manufacturer's shop

On site, the gear set was installed during a major overhaul. Before the gear unit was opened, the levels on the casing were checked. The check with precision levels indicated that the casing alignment was very good, with the two level readings having a deviation of 0.01 mm/m (see

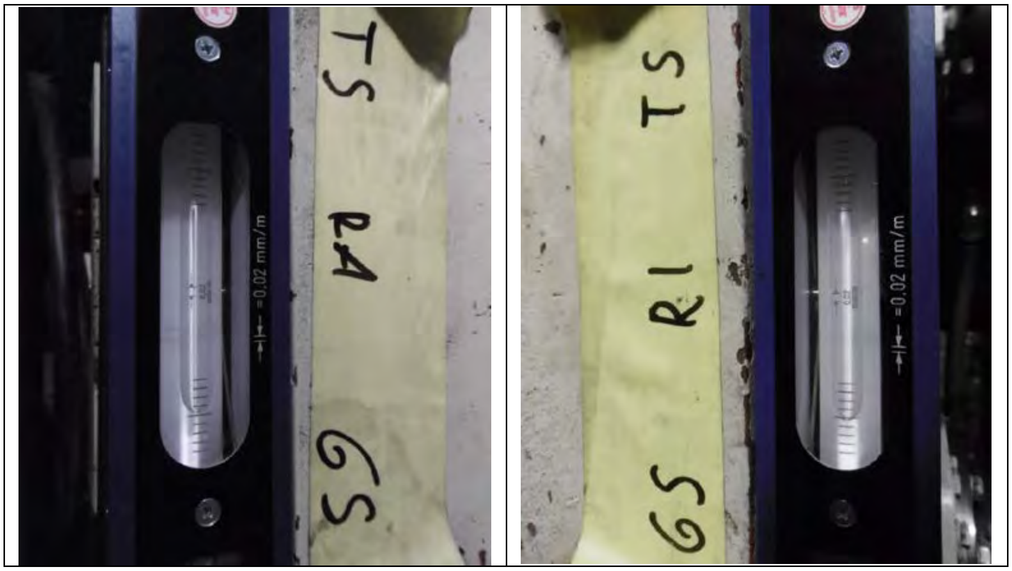


Figure 12) between each other, while the specified limit was 0.02 mm/m.

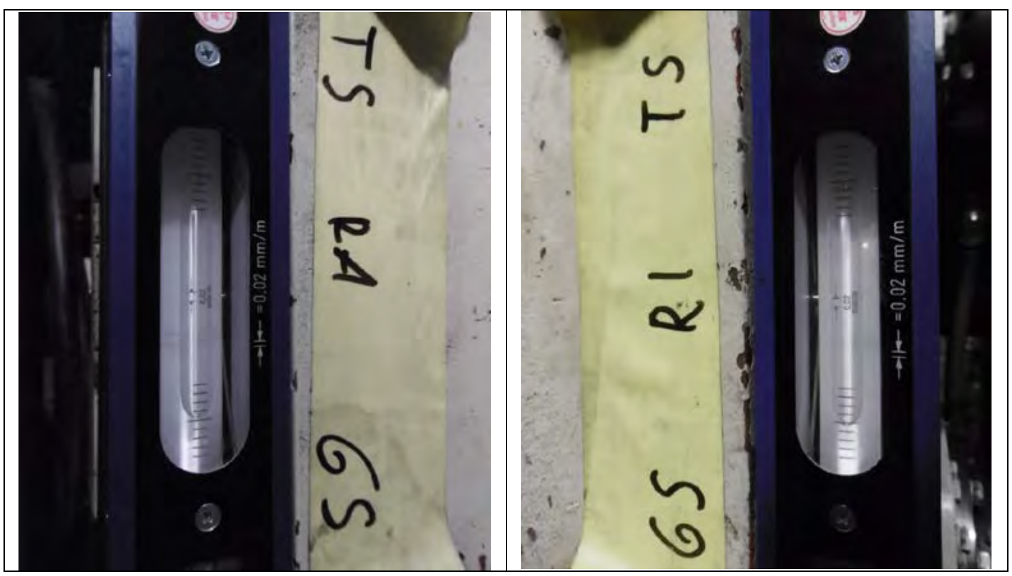


Figure 12. Spirit Level check on site

After the casing upper part was removed, the level check was repeated. The levels were the same as shown in Figure 7. This confirmed that the casing position remains the same, no matter if the casing upper part is installed or removed. This corresponds to the experience gathered by the author's company with all gear units.

Based on this, the way forward could have been to install the gear set, check the levels on the open casing, re-install the upper casing and check the levels again. Nevertheless, the user insisted on doing a blue ink check after the installation of the spare gear set. Accordingly, a blue ink check was performed in addition with the spare gear set being installed in the casing lower part and the upper casing part being removed. The result of this blue ink check is shown in Figure 13.

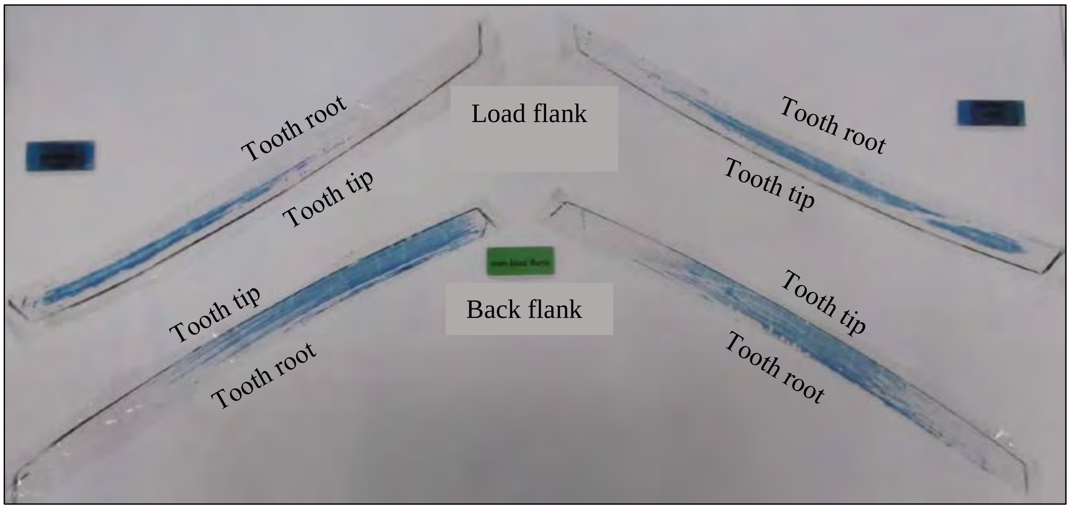


Figure 13. Tooth contact check (blue ink check) on site

The tooth contact was good and looked the same as during the blue ink check performed in the gear manufacturer shop (see Figure 11). The casing levels were checked in this situation too. Both levels were unchanged, the same as shown in

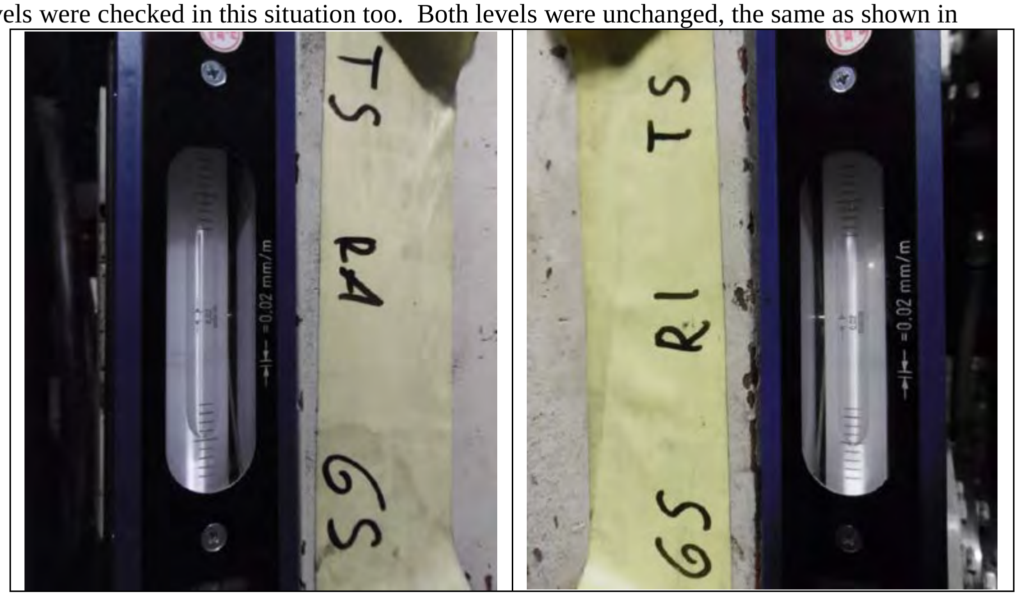


Figure 12. Altogether, these checks confirmed once more that the level check is a reliable representation of the tooth contact in the gear mesh.

CASE B: STRING TEST WITH A GEAR CASING NOT BEING ALIGNED WITHIN TOLERANCE

A gear unit rated for 7500 HP at an input speed of 1800 rpm and an output speed of 11808 rpm was delivered to be used in a motor-compressor application with variable speed. Before the start of a string test at the compressor manufacturer, it was detected that the gear casing was not properly aligned on the test stand. The deviation between the two level readings was 12 mm/m, exceeding the design limit of 0.02 mm/m specified in the gear unit manual. Accordingly, the tooth contact was compromised.

On the other hand, the test run was planned to be a part load test only. It was scheduled to run a no load test at maximum continuous speed and a test with 23% of nominal torque at minimum speed. The question was raised if the gear unit could handle the reduced load even with the internal misalignment revealed by the level check.

The angle α_0 (angular deviation between the two level readings on the reference bars) was known from the measurements: α_0 = 12 mm/m = 0.012 radian. The center distance of the gear unit is CD = 630 mm. The distance between the reference bars (length of the casing) is 1850 mm. Using these values in equation 6, the angular deviation $\Delta\alpha$ between the two gear shafts (internal misalignment between the shafts) can be calculated:

$$\Delta\alpha = \alpha_0 * \frac{CD}{L} = 0.012\, radian * \frac{630\, mm}{1850\, mm} = 0.04\, radian$$

From that value, the resulting gear tooth lead mismatch and the correlated lead modification factor K_H was calculated. By taking that factor and the reduced load of 23% of nominal torque into account, it was possible to demonstrate that the maximum local contact stress on the gear flanks as well as the maximum local bending stress in the teeth were still below the allowable stress numbers. It was approved to run the string test at no load and part load (23% of nominal torque) with the gear unit as installed.
The string test was performed successfully. After the test, the gears were visually inspected through the inspection hatch. It was confirmed that the gear flanks were still in perfect condition.

CASE C: REVEALING BAD TOOTH CONTACT AND CORRECTING IT

An Integrally Geared Compressor was inspected and overhauled after a failure in one compressor stage. The unit consists of 5 compressor stages driven by an electric motor, connected to the bull gear shaft, and a steam turbine, connected to a pinion shaft (pinion 4) situated below the bull gear shaft. The gears are rated according to AGMA 421.06 for a total power of 21800 kW (29235 HP). The first two compressor stages are attached to one pinion (pinion 1), stages 3 and 4 are attached to another pinion (pinion2) and the compressor stage 5 is attached to a third pinion (pinion 5). Pinions 1 and 2 are situated together with the bull gear shaft in the horizontal main split line of the gear casing (see Figure 14). Pinion 3 is located on top of the bull gear shaft in an additional split line of the gear casing. Two reference bars are mounted to the gear casing on support faces that are coplanar with the main split line of the casing (see Figure 14).

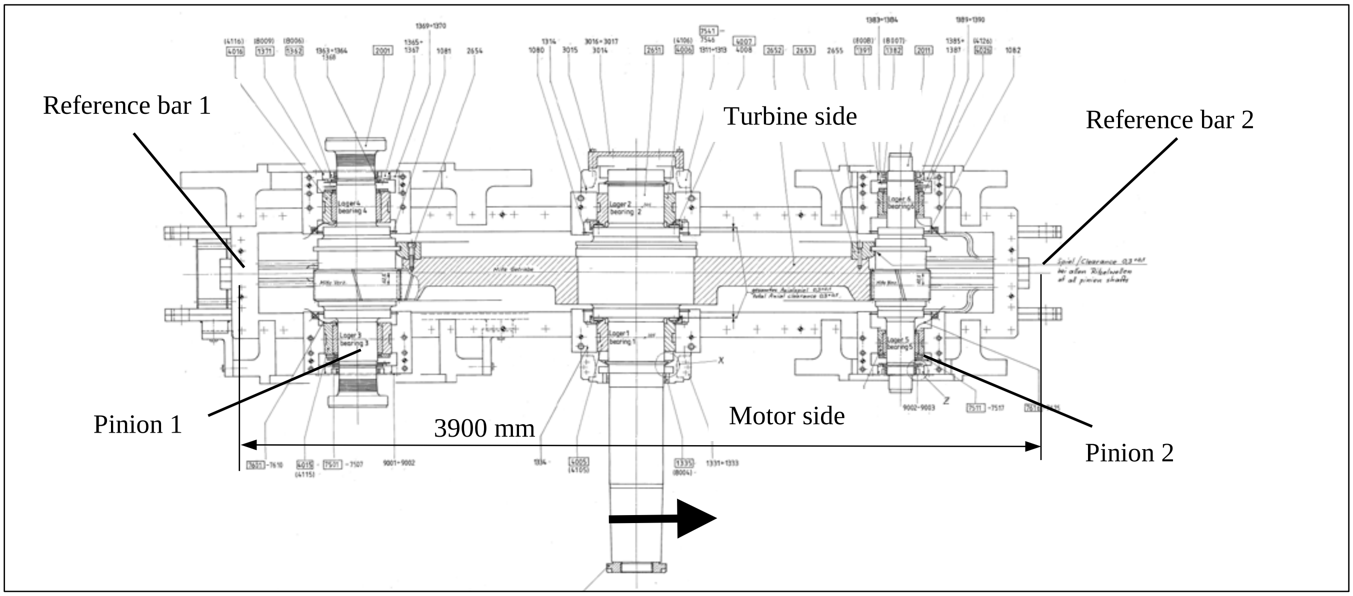


Figure 14. Gear unit Integrally Geared Compressor (Case C). View on the split line

During the inspection of the gear unit, the level check indicated a strong distortion of the casing. The two reference bars were not parallel to each other. Compared to reference bar 2, the turbine side end of reference bar 1 was higher by 0.15 mm. A blue ink check was performed in addition and indicated that the tooth contact was displaced towards motor side – see Figure 16 for the contact pattern of pinion 1. The correct tooth contact should be in the center – see Figure 15 with the blue ink check results as recorded for pinion 1 in the gear manufacturer's shop, with the rotors installed in the casing.

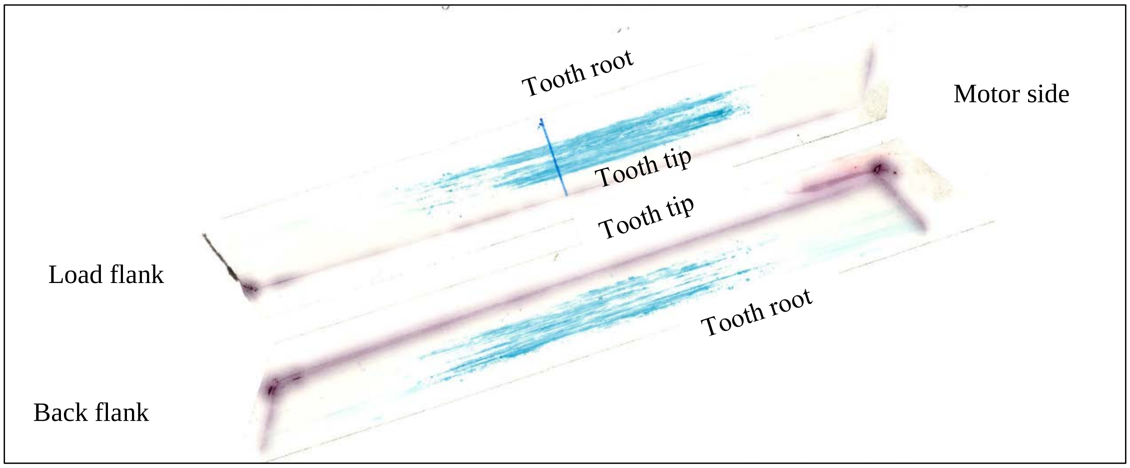


Figure 15. Tape lift record of blue ink check on pinion 1, at the gear manufacturer's shop

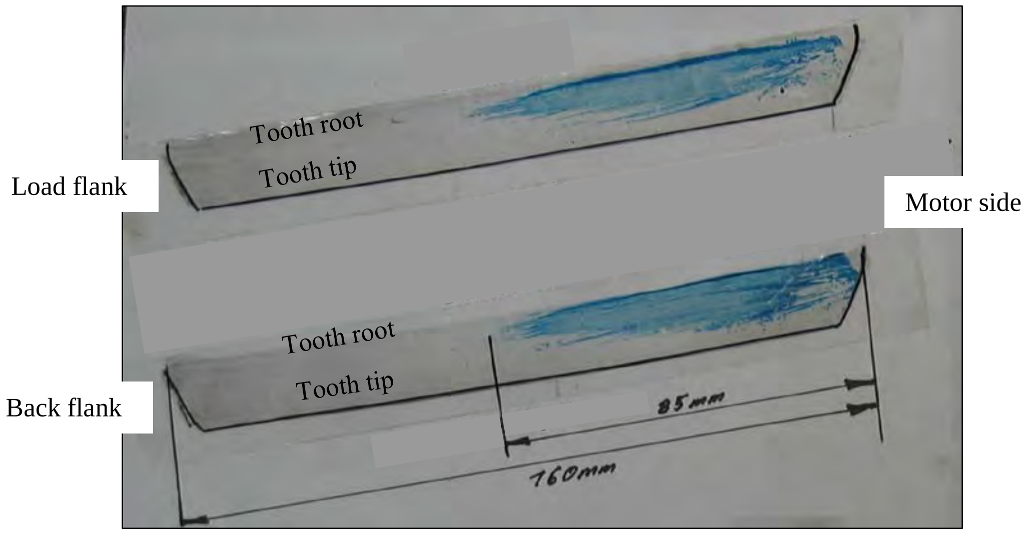


Figure 16. Tape lift record of blue ink check on pinion 1, before correcting the casing distortion

It was decided to correct the improper installation of the gear casing by placing a shim plate below the corner of the casing under bearing 3 (below pinion 1, motor side). Two plates were prepared, one with a thickness of 0.3 mm and one with a thickness of 0.4 mm. In a first try, the 0.3 mm shim plate was installed and the tooth contact was checked, then the 0.4 mm plate was installed and the tooth contact was checked again. No records are available for the try with 0.3 mm.

Level checks and blue ink checks with the 0.4 mm plate indicated good results. The level readings on the two reference bars differed by 0.03 mm/m with the turbine end of reference bar 1 being higher by 0.03 mm/m compared to the reference bar 2. The allowable value is 0.04 mm/m. The blue ink check records indicated the tooth contact patterns of all pinions slightly shifted out of center towards motor side, but within tolerance – see Figure 17.

A thicker shim plate could have improved the tooth contact further but it was decided to leave the 0.4 mm plate installed.

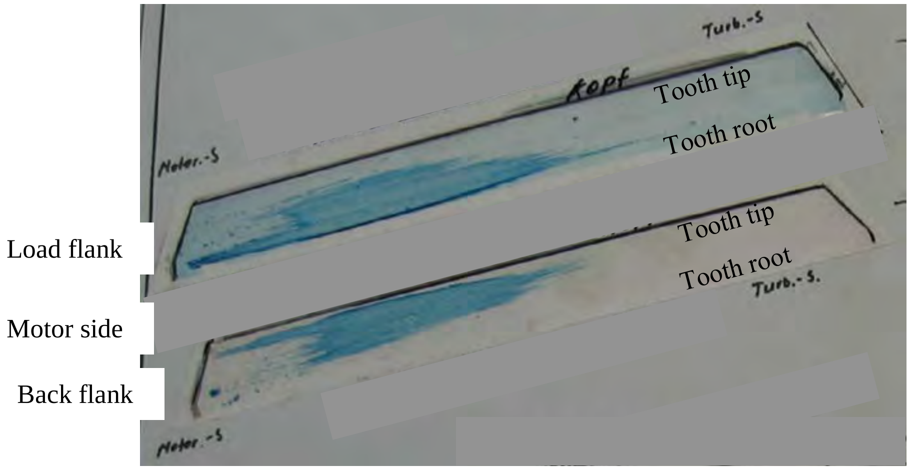


Figure 17. Tape lift record of blue ink check on pinion 1, after correcting the casing distortion

The unit was put into operation. It has been operated successfully for 13 years and still is in operation.

CONCLUSIONS

This paper describes an advanced method to check the tooth contact of a gear unit.

To perform the check, only a small wrench and a precision frame spirit level are needed; both are commodity tools. Two reference bars must be provided on the gear casing on which the frame spirit level can be placed. The purchaser has to specify this prior to ordering the gear unit. Providing the bars is easy; their design is simple. Precise manufacturing of the reference bars and of the support faces for the reference bars is necessary in the gear manufacturer's shop.

The method has been used for many years on gear units and has proven itself in the field as reliable. In addition, the method is easy and quick to perform (practical). It can be performed during operation and at standstill. No blue ink test is required. The gear unit does not have to be opened, not even its inspection cover. No anchor bolts need to be released. Thus, the time needed to check the tooth contact is strongly reduced. The check can be performed within regular time intervals by the operating staff within 20 minutes. In total, the quality of installation and maintenance is improved while at the same time work can be completed faster.

NOMENCLATURE

Lead modification: an intentional deviation from the ideal helix angle; it refers to the tooth flanks of gears
Precision spirit level: a spirit level with a high sensitivity; one unit on the scale shall be 0.02 mm/m or less
Shaft spirit level: a spirit level with a V-shaped groove on its base face; it can be placed on a cylindrical part like a shaft

FIGURES

APPENDICES

Appendix A: drawing of a reference bar
Appendix B: drawing of a support for a reference bar

REFERENCES

[1]: API Standard 613, Special Purpose Gear Units for Petroleum, chemical and Gas Industry Services, Fifth Edition, February 2003
[2]: John Piotrowski, Shaft Alignment Handbook, Third Edition, 2007 by Taylor & Francis Group, LLC

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