Rub Tolerant Labyrinth Seals

A Simple Method for Estimating the Effect of Upgrading Your Compressor

Try this on your compressor to see if you can benefit from a conversion to rub tolerant seals.

Degradation of labyrinth seals in centrifugal impellers can have a significant impact on not only compressor power consumption but also on the plant production rate. Upgrading to rub tolerant seals can be beneficial in not only making improvements to the current efficiency and capacity but even more importantly maintaining it at these new improved levels. With damaged labyrinth seals, the head and efficiency are reduced. The performance curve is shifted down and to the left and the capacity of the compressor is reduced, thus limiting plant output.

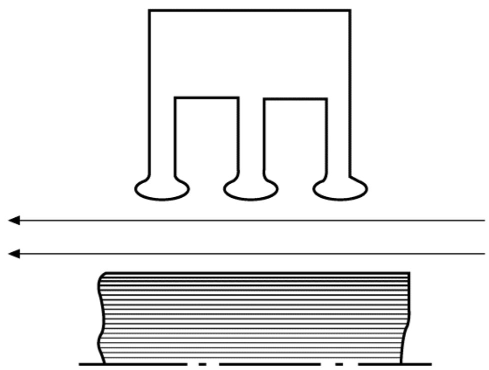

Figure #1

Figure 1. Damaged labyrinth seal. Such damage can occur in an instant as the compressor goes through the critical speed on start up. This then results in the remaining run of the compressor (for 2, 3, 4 years or even longer) with these increased clearances and resulting efficiency losses.

With rub tolerant seals installed, the shaft may deflect during a vibration excursion, such as passing through a critical speed, and contact the seal. The seal teeth deflect then return back to as-installed when the vibration level settles back to normal. Seal clearances remain at design clearances, thus compressor performance is maintained.

For a closed impeller with a labyrinth seal at the impeller eye, the leakage through the impeller eye seal is recirculated through the impeller. This leakage is recompressed and the compressor efficiency is affected in proportion to the amount of flow being recycled. The same is true for the impeller shaft labyrinth and the balance piston labyrinth.

For example, let's assume you have a compressor with 4 impellers. The compressor main inlet pressure is 200 psia (13.8 bara) and the discharge pressure is 315 psia (21.7 bara). To keep things simple, let's assume the pressure ratio for each impeller is the same.

$R_p^x = P_2/P_1$

or:

$R_p = (P_2/P_1)^{1/x}$

Where:

R_p = Pressure ratio across each compressor stage.

X = # of impellers

P_1 = inlet pressure

P_2 = discharge pressure

For this example:

$R_p = (315/200)^{1/4}$

$Rp = 1.12$

The pressure ratio is approximately 1.12, so the pressure following the 1st wheel is 224 psia (15.4 bara). Assuming that the pressure development through the impeller is approximately 60% of the stage pressure rise (the rest of the pressure rise is in the diffuser – see Fig. 5), this gives us a pressure of 214.4 (14.8 bara) at the impeller tip and at the impeller eye seal area.

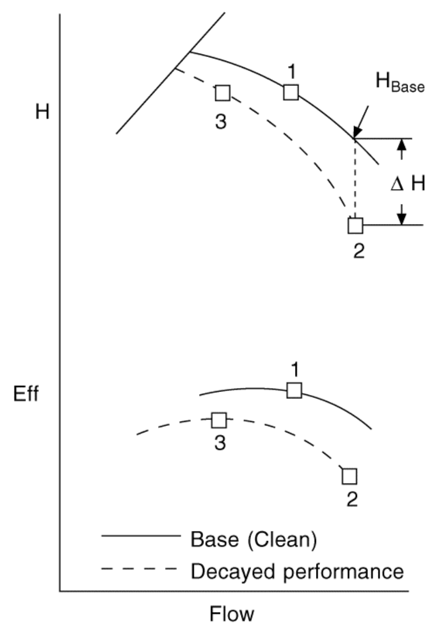

Figure #2

Figure 2. The solid line represents the compressor in like new condition, clean and with the labyrinth seals per design specs. With damaged labyrinth seals, the head and efficiency are reduced. The performance curve is shifted down and to the left and the capacity of the compressor is reduced, thus limiting plant output. Rub tolerant seals can be installed with clearances that are smaller than the original aluminum labyrinths, so both head (pressure rise), efficiency (power) and compressor through flow will be improved over the original equipment.

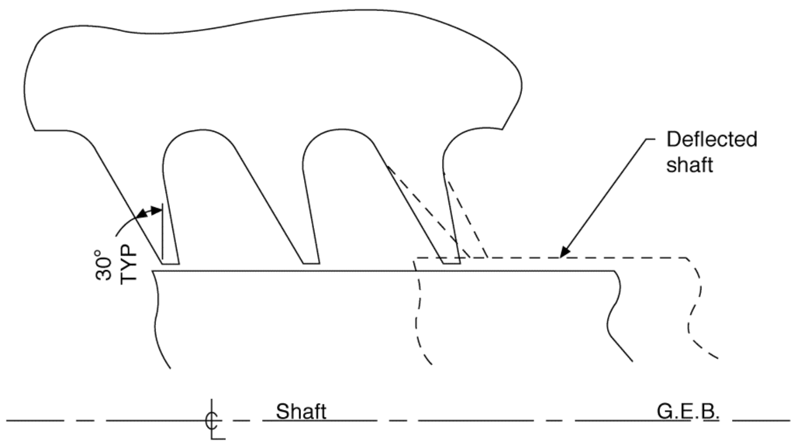

Figure #3

Figure 3. Rub Tolerant Seal. The shaft may deflect during a vibration excursion, such as passing through a critical speed, and rub the seal. Since the seal material is flexible, the angled seal teeth deflect then return back to normal when the vibration level settles back to normal.

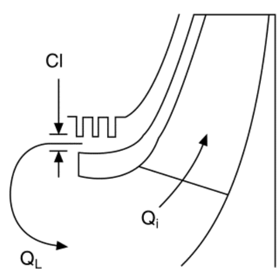

Figure #4

Figure 4. Closed impeller with labyrinth seal at impeller eye. Leakage through the impeller eye seal Q_L is recirculated through the impeller. The compressor efficiency is affected in proportion to the amount of flow leaking through the impeller eye labyrinth seal Q_L, relative to the main gas flow, Q_i. The same is true for the impeller shaft labyrinth and the balance piston labyrinth. For a closed centrifugal impeller, the efficiency loss for increased eye labyrinth seal clearances is about one percentage point for each percent increase in Q_i (as a result of Q_L increasing and inlet flow to the compressor constant).

So, for closed centrifugal impellers with labyrinth seals at the eye, the following rule of thumb may be used:

$$\%\Delta\eta \propto -\%\Delta Q_i$$

Where:

Q_i = *Impeller flow*

Using a software program based on the Adolf Egli procedure (free download), you can easily calculate the seal leakage for the impeller eye seal for the standard seal and proposed new rub tolerant seal.

From the OEM manual, obtain the radial seal clearance for the first stage impeller and the eye seal diameter. Knowing this information and the gas analysis, enter the values into the labyrinth seal leakage program. Approximate the value for the radial seal clearance for the new rub tolerant seals by:

$$CL_{RT} = CL_{brg} + D_{Eye}/8000$$

Where:

CL_{RT} = Radial clearance for the new rub tolerant seals, inches

CL_{brg} = Radial clearance for the compressor journal bearings, inches

D_{Eye} = Impeller eye diameter at the eye seal, inches

For this example:

CL_{RT} = 0.0025" + 14/8000

CL_{RT} =0.004"

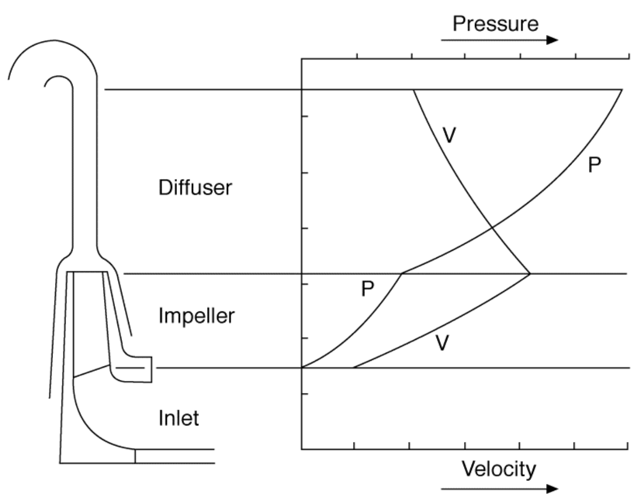

Figure #5

Figure 5. Velocity/pressure development through a centrifugal compressor stage. A rule of thumb used by one OEM is that approximately 60% of the pressure is developed in the impeller. The rest of the pressure rise for a stage is developed in the diffuser as noted above. Note that this is a crude rule of thumb and not a precise calculation. This value can vary depending on the stage design and operating conditions. Accurate values can be obtained from software prediction programs that model the compressor in detail.

If the compressor through flow is 2500lb/min, then the efficiency improvement is: (48-11)/2500 => 1.5% if the impeller eye seals are changed out to rub tolerant seals. Note that this is relative to aluminum seals in the as new condition. Often the aluminum seals may be worn out and may be more than two or three times the normal spec clearances.

Changing out the impeller shaft seals and balance piston seals will result in even more improvement.
For an accurate assessment, use a software program that properly models the compressor aerodynamically to confirm both the efficiency & power improvements and capacity enhancement.

Use a software program to continuously monitor the compressor before and after change out of the labyrinth seals to demonstrate the improvement in compressor performance.

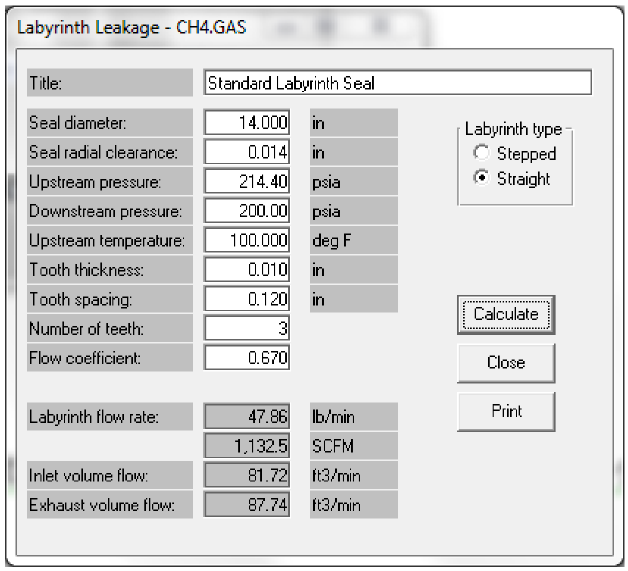

Figure #6

Figure 6. Leakage rate for the first stage impeller with standard aluminum labyrinth seals is 48 lb/min. as calculated based on the Egli procedure. Assume the other three stages will be similar. Recalculating the leakage rate for the first stage impeller with rub tolerant labyrinth seals gives us 11 lb/min. Note that if you assume the aluminum labyrinth seals will eventually open to two times the normal clearance (leakage = 71lb/min), the efficiency improvement for the change out to rub tolerant seals will be: (71-11)/2500 => 2 ½%. This calculation is based on change out of all of the impeller eye seals. Changing out the impeller shaft seals and balance piston seals will result in even further efficiency improvement.

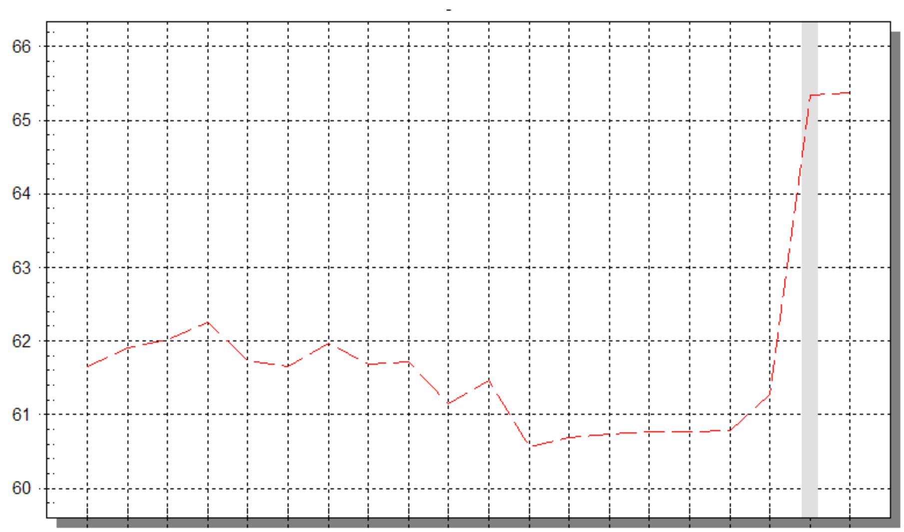

Figure #7

Figure 7. Plot of compressor efficiency vs. time. Monitor the compressor before and after change out of the labyrinth seals to demonstrate the improvement in compressor performance.

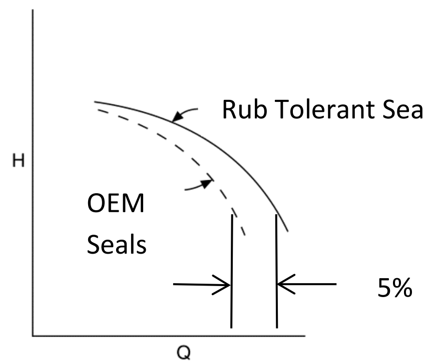

Figure #8

Figure 8. You can expect capacity improvement of 5% or more depending on the slope of the head curve, where the machine is operating on the curve and how the compressor chokes. Changing out the impeller shaft seals and balance piston seals will result in even more capacity (plant output).

Reference: "Compressor Performance: Aerodynamics for the User", M. Theodore Gresh, Flexware, 2011

Ted Gresh
Flexware, Inc.
&
John Whalen
John Crane Engineered Bearings
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Ted Gresh is president, Flexware, Inc., Grapeville, Pennsylvania, U.S.A. He has been involved in the design of high efficiency centrifugal compressor staging, field-testing of compressors and steam turbines and troubleshooting field performance problems for over 40 years. While most of this time was in the Technical Services Dept of Elliott Co., Jeannette, PA, USA, he is presently with Flexware, Inc. a company focused on turbomachinery engineering consulting services, training seminars and software for turbomachinery performance analysis. Gresh received a B.S. degree (Aerospace Engineering, 1971) from the University of Pittsburgh. In addition to numerous papers and magazine articles, he has published a book on the subject of compressor performance, and has several patents related to turbomachinery. He is a registered Professional Engineer in the State of Pennsylvania. You can contact him at his e-mail address: mtgresh@flexwareinc.com

John K. Whalen, PE is the Chief Engineer for John Crane Engineered Bearings. John is a member of STLE, ASME, and the Vibration Institute and is a member of the Turbomachinery Symposium Advisory Committee; John is a registered Professional Engineer in the State of Texas.

John received his BSME from the Rochester Institute of Technology in 1981. He worked for Dresser Rand where he was involved in Large Turbine Engineering and Rotordynamics. John joined Centritech Corporation in 1988 and helped form TCE/Turbo Components & Engineering in 1991. TCE was acquired by John Crane in 2011.

John Crane Engineered Bearings product range includes babbitted bearings and seals, labyrinth seals, and related products and services.