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Comparing the Lateral Behaviour of a Boil off Gas Compressor with Dry and Wet Seals

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ABSTRACT

This paper focuses on the comparison of the lateral behavior of wet (oil) seals with dry (gas) seals for boil off gas compressors in the liquefaction of Liquefied Natural gas (LNG), to ascertain the possibility/technical feasibility of dry gas seal retrofitting (or complete replacement). Two compressors, the High pressure and Low pressure compressors were considered. For the conditions considered, the critical speeds and Amplification factors were calculated for both the low pressure and high pressure centrifugal compressors. This calculation was carried out for compressors with the original wet (oil) seal and the retrofitted dry gas seal. The results showed that the lateral behavior of the retrofitted compressor is similar to that with wet (oil) seal as the amplification factors of the critical speeds remained approximately the same. The calculated critical speeds were slightly shifted downward for the retrofitted conditions due probably to the increased mass of the new seal configuration. Thus it can be conclusively inferred that the lateral behavior of both the low pressure (LP) and high pressure (HP) boil off gas (BOG) compressors are hardly affected by the retrofit or complete replacement to dry gas seal.

Keywords: *Boil off gas, LNG, retrofitting, lateral behavior, wet oil seal, dry gas seal, critical speed, amplification factor.*

1. INTRODUCTION

Centrifugal compressors are widely used in the production and transmission of natural gas. Seals on the rotating shafts prevent high-pressure natural gas from escaping the compressor casing. Traditionally, these seals used high-pressure oil as a barrier against escaping gas. Reliability problems of these wet (oil) seals such as short mean time between failure intervals, high methane gas emission, high operating and maintenance costs and shorter equipment life span have always been a major problem for gas processing companies. Most companies have found out that replacing these wet (oil) seals with dry gas seals are technically feasible and also provide the solution for the problems associated with wet (oil) seals. For instance, Natural gas STAR partners have found out that replacing a wet (oil) with dry gas seal can save up to $135,000/year; reduce methane emissions by 97% saving about $80, 000/year in gas alone with a payout time of just 14months. They also found out that replacing with dry seals reduced the power requirements with dry seals lasting twice as long as wet seals (Natural gas STAR partners, 2003).

The retrofitting or complete replacement of wet seals with dry seals is expected to introduce certain dissimilarities in the lateral behavior of the retrofitted compressor compared to the original compressor with wet (oil) seal. This paper compares the lateral behavior of the original wet (oil) seal with that of the retrofitted gas seal.

1.1 Lateral Behavior

1.1.1 Rotor Dynamics

Rotor dynamics is the science of predicting the vibrational behavior of rotors of any kind. (Brian, 2007). By lateral vibrations we mean the translator oscillations of the axis of the rotor in the planes orthogonal to the axis of rotation (Rudolf and Hans, 2009). In this paper the vibrational behavior of the rotors in the wet and dry seal compressors is analyzed with respect to rotor speed (critical speed) and amplification factor.

Using the definition according to the API dynamics section, critical speeds correspond to the resonance frequencies of the rotor-bearing support system. The basic identification of critical speeds is made from the natural frequency of the system and of the forcing phenomenon. If the frequency of any harmonic component of a periodic forcing phenomenon is equal to or approximates the frequency of any mode of rotor vibration, a condition of resonance may exist. If resonance exists at a finite speed, that speed is known as the critical speed (Wachel, 1990).

The evaluation of rotor stability has become an important aspect compressor design. Self excited instabilities have been responsible for millions of dollars of down time, lost production and high maintenance cost as rotor performance continues to increase. High speed centrifugal compressors are particularly susceptible to destabilizing effects from wet (oil) seals. Rotor stability is usually expressed in terms of the system logarithmic decrement, which is a measure of the system damping. (Atkins, Perez and Turner; 1994). The basic concepts involve solving the equations of motion for the rotor bearing system and computing the damped natural frequency. The damped natural frequency is a complex quantity of the form;

$$S = \lambda + iw \tag{1}$$

λ = damping exponent
w = undamped natural frequency

The logarithmic decrement δ is defined as

$$\delta = \frac{-2\pi\lambda}{w} \tag{2}$$

The logarithmic decrement is also related to the system Amplification factor, AF, according to the equation

$$\delta = \frac{\pi}{AF} \tag{3}$$

Where

$AF = \frac{1}{2\zeta}$ and ζ = damping ratio

For values of $\lambda < 0$; the system is considered stable.
For values of $\lambda > 0$; the system is considered unstable.

2. COMPRESSORS UNDER STUDY

The compressors under study are centrifugal compressors for natural gas liquefaction in the Nigerian liquefied natural gas (NLNG) Facility. They are specifically meant for liquefying Boil off gas (BOG) in the LNG compressor trains. It consists of two (2) centrifugal compressors, each arranged in series driven by a fixed speed induction motor through a speed increasing gear box. They are equipped with oil lubricated face and bushing seals. On the other hand, the dry gas retrofitted compressors have similar configurations as the original oil seal compressors for the High pressure (HP) compressor with only a little modification made in the Low pressure (LP) compressor seal housings.

Both the HP and LP compressors are

- ✓ Designed as in line compressors.
- ✓ Equipped with a balanced drum at the discharge side to balance aero dynamics thrust load.
- ✓ Seal against the suction pressures.

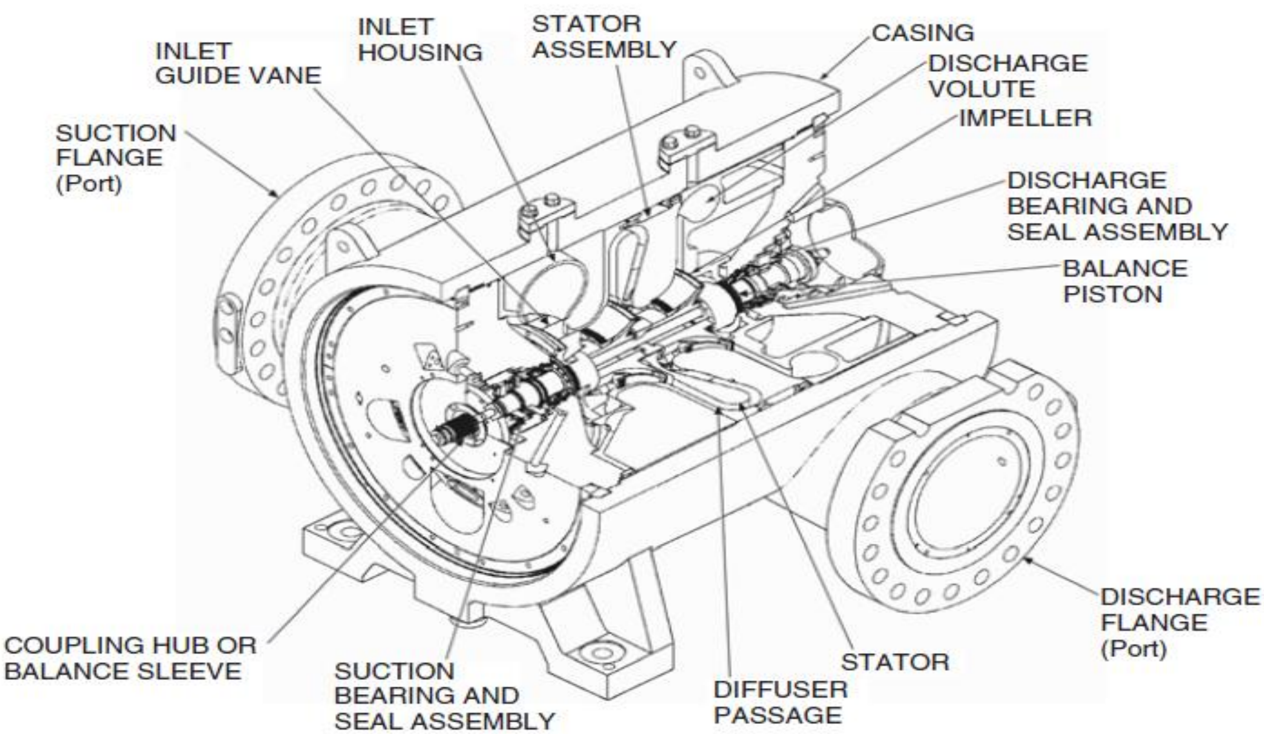

Fig 1: Typical centrifugal compressor cutaway, Courtesy GPSA, 2004

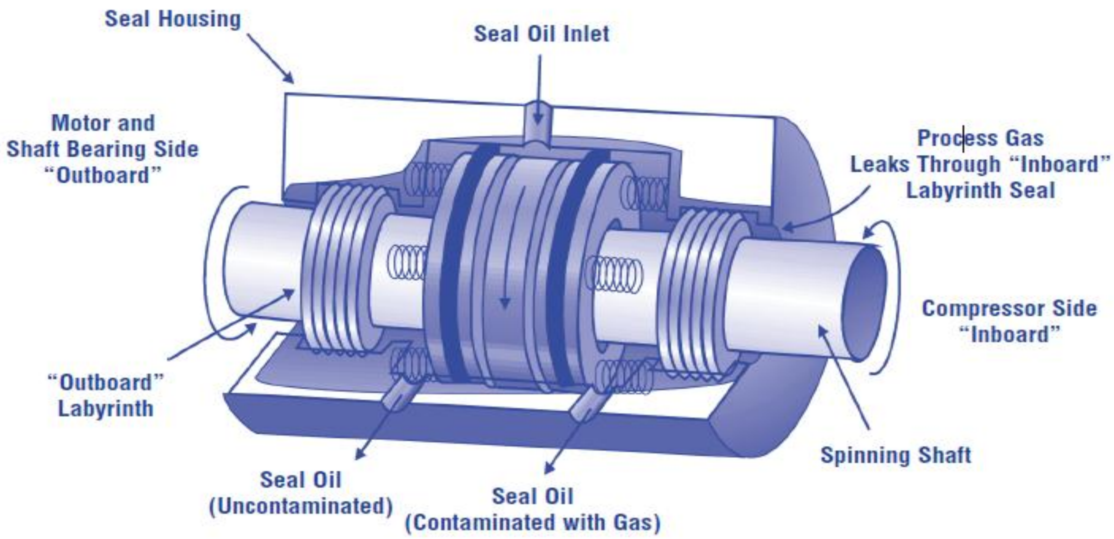

Fig 2: Diagram of a wet (oil) seal. (Courtesy of Natural Gas STAR partners, 2003)

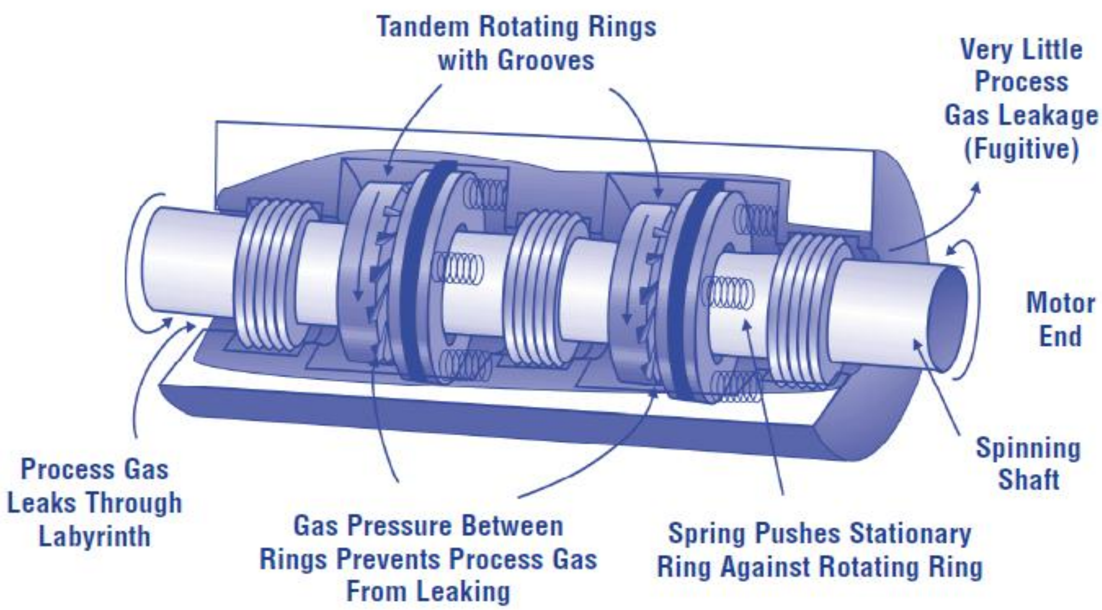

Fig 3: Diagram of a dry (gas) seal. (Courtesy of Natural Gas STAR partners, 2003)

3. RESEARCH METHOD

3.1 Lateral Speed Analysis

Lateral critical speed calculations were carried out on both the original oil seal system and the newly converted dry gas seal system. This was done so as to observe if there are any changes in the rotor dynamics of both systems which can indicate either a failure or a success in the conversion to dry gas seal systems. The lateral behavior checked for included:

- Nominal clearance, nominal preload and normal lube oil supply temperature of 60^{o}C
- Minimum clearance, maximum preload and lube oil supply temperature of 55^{o}C
- Minimum clearance, maximum preload and lube oil supply temperature of 65^{o}C
- Maximum clearance, minimum preload and a lube oil supply temperature of 55^{o}C
- Maximum clearance, minimum preload and a lube oil supply temperature of 65^{o}C

The analysis was carried out for both the High pressure (HP) and low pressure (LP) compressors

4. ANALYSIS OF THE RESULTS AND DISCUSSIONS

The results of the calculations demonstrate that the lateral behavior of the retrofitted compressor is similar to that with the original wet (oil) seal as the amplification factors of the critical speeds remained approximately the same. The calculated critical speeds are slightly shifted downward for the retrofitted conditions due probably to the increased mass of the new seal configuration. Thus it can be conclusively inferred that the lateral behavior of both the low pressure (LP) and high pressure (HP) boil off gas (BOG) compressors are hardly affected by the retrofit or complete replacement to dry gas seal.

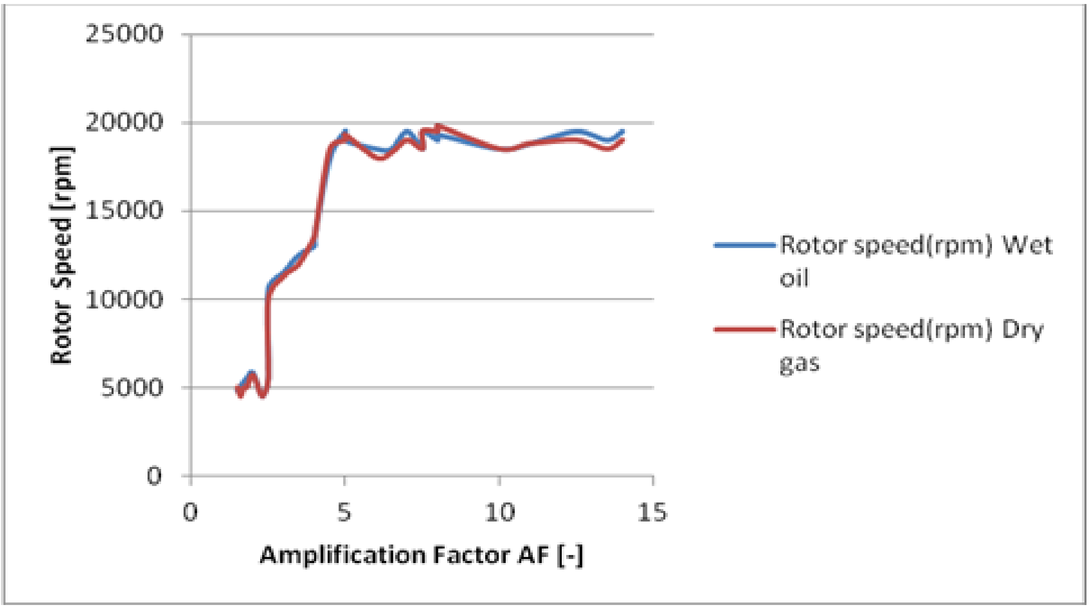

Fig 4: Chart showing Critical speed against Amplification factor for LP (BOG) compressor

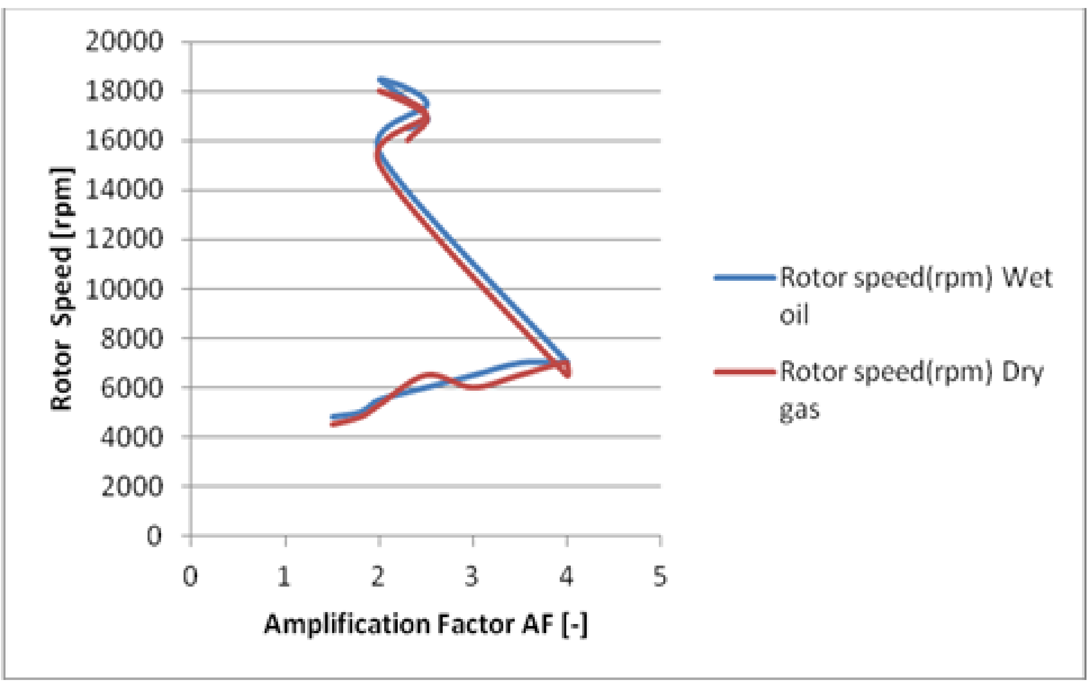

Fig 5: Chart showing Critical speed against Amplification factor for HP (BOG) compress

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