International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 09 | Sep 2022 www.irjet.net p-ISSN: 2395-0072

"Design and development of better alternatives to shrink fit achieved by induction heating in rotor shaft assembly of the hermetically sealed reciprocating compressor"

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Abstract - In rotor shaft assembly of hermetically sealed reciprocating compressor, there is interference fit between rotor and shaft. To obtain this interference fit various methods are used. Without the use of extra mechanical fastening systems, interference-fitted joints are an efficient and cost-effective way to assemble components. An interface pressure is established during assembly by press-fitting or a shrink-fitting assembly process as a result of a dimensional misfit between the two parts, which is frequently in a shaft and rotor. Because of frictional resistance, the joint is able to withstand axial forces and torques. The traditional method for achieving a shrink fit between the rotor and shaft is induction heating. This process requires heating equipment and higher energy consumption, this will increase the manufacturing cost of the compressor. Due to the limitations of induction heating process, there is a need to identify and design an alternative options for achieving shrink fit in rotor shaft assembly in cost effective manner yet ensuring the desired quality. This paper presents the study of current and proposed assembly procedure used to get rotor-shaft assembly in hermetically sealed reciprocating compressor. In this study, factors that affect an interference-fitted joints' ability to function properly are grouped under a few general headings, including: coefficient of friction, coefficient of thermal expansion, surfaces, the geometry, frictional force, torque, tangential force, materials, loading, and lastly the assembly method utilized to create the joint between the rotor and shaft.

***Keywords*: Interference fit, , rotor shaft assembly, shrink fitting, induction heating, radial or interface pressure, torque, frictional force, tangential force.**

1. INTRODUCTION:

In rotor shaft assembly of the hermetically sealed reciprocating compressor, to achieve an interference fit between rotor and shaft, shrink fitting techniques are generally used. Shrink fitting typically refers to techniques that utilize the phenomena of thermal contraction and expansion to produce an interference fit. The most common method for doing this is to heat the outer component, causing it to expand thermally. Then two parts fit together easily. An incredibly tight joint forms around the inner part when the outer part cools to room temperature and contracts back to its original size. Typically, metals will expand in response to heating. So induction heating is generally used to obtain shrink fit in rotor shaft assembly. In existing induction heating process rotor is heated from outside surface and then heat is transferred from outside to inside surface of rotor to obtain thermal expansion of rotor bore. After expansion, rotor is shrink fitted into the shaft. But this process requires higher power consumption and hence increases the manufacturing cost of the compressor. So heating from the inside surface of the rotor bore is the alternative option to achieve shrink fit in rotor shaft assembly.

2. Rotor Shaft Assembly:

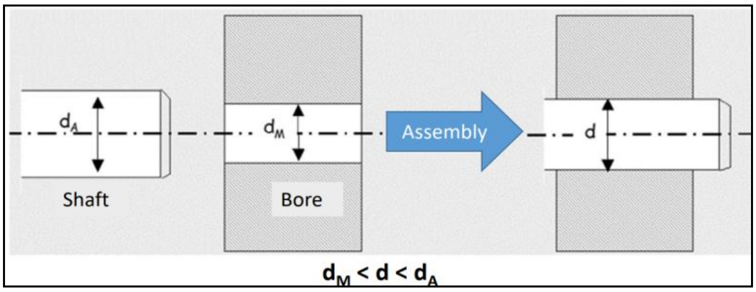

Figure 1.Dimensions of rotor and shaft interference fit prior to assembling

d_A = Outside diameter of shaft

d_M = Inside diameter of rotor

d = Diametric interference

Figure shows the dimensions of rotor and shaft interference fit prior to assembling. Interference fit is also known as press fit or friction fit, is a fastening method where two parts, typically circular cross section shape, are pushed together (one into the other) and kept in place due to the pressure between them. Typically, the inner part will have a nominal outer diameter slightly greater than the nominal inner diameter of the outer part, and when pushed or forced together the contact friction forces keep the parts from moving relative to each other. The level of interference depends on the negative difference in nominal diameters.

Shrink Fit Process

Obtaining shrink fit by heating from the inside surface of the rotor bore:

The only viable way to heat the rotor is using an induction coil from the inside surface of the of the rotor bore, this heat allows for better energy delivery to the assembly. In this method heating will be only local heating. An induction coil can be used to heat the rotor bore. The coil is inserted into the rotor bore and power is applied for certain time to reach the required temperature for heating the rotor bore and tried to expand the rotor bore and placed onto the shaft. This process consumes less power as compared to heating from the outside surface of rotor.

Theoretical modelling of Thermal expansion:

Part	Material	Outside diameter (mm)	Inside Diameter(mm)	Stack Height(mm)	Coefficient of Thermal expansion(mm/mm^{0}c)
Rotor	Aluminium	60.3	19.5	63.5	23.1×10^{-6}

Table 1: Dimensions and material properties of aluminium rotor

Diameter increase of rotor bore when being heated or Thermal expansion of rotor bore is calculated as:

$\Delta d = d_o \alpha \Delta T$

Where,

Δd = change in diameter of rotor bore or thermal expansion (mm)

d_o = inside diameter of rotor at initial temperature (mm)

α = coefficient of thermal expansion of aluminum, 23.1×10^{-6} (mm/mm^{0}C)

ΔT = change in temperature (^{0}C)

Room temperature =27 ^{0}C

Original diameter of rotor bore (mm)	Temperature (^{0}C)	Thermal expansion of rotor bore (mm)	Increased diameter of rotor bore (mm)
19.5	50	0.01	19.51
19.5	80	0.023	19.523
19.5	100	0.032	19.53
19.5	150	0.05	19.55
19.5	200	0.07	19.57
19.5	225	0.089	19.58

Table 2: Theoretical modelling of Thermal expansion

Experimental method for obtaining required thermal expansion of rotor bore by heating from inside surface of rotor bore:

Rotor Material	Rotor outside diameter (mm)	Rotor inside diameter (mm)
Aluminium	60.3	19.5

Table 3: Dimensions of aluminium rotor bore

Process: A 2 KW cartridge heater rod is used to heat the rotor bore. The rod is inserted into the rotor bore and power is applied for time to reach the required temperature at which thermal expansion of rotor bore is obtained. In this process tried to expand the rotor bore at various temperature. Temperature is measured by thermocouple. Thermal expansion is measured by digital vernier caliper having least count of 0.01mm.

Figure 2. Cartridge Heater Rod

Figure 3. Aluminum Rotor

Figure 4. Experimental Setup

Figure 5. Thermal Expansion of aluminium rotor bore

Experimental Result:

Original Diameter of rotor bore(mm)	Temperature(ºC)	Thermal expansion(mm)	Change in diameter of rotor bore(mm)
19.5	50	0.03	19.53
19.5	80	0.06	19.56
19.5	100	0.08	19.58
19.5	150	0.18	19.68

Table 4: Experimental results of thermal expansion

Temperature(^{0}C)	Thermal Expansion	
	Theoretical (mm)	Experimental(mm)
50	0.01	0.03
80	0.023	0.06
100	0.032	0.08
150	0.05	0.18
200	0.07	0.25
225	0.08	0.33

Comparison of Theoretical and Experimental result

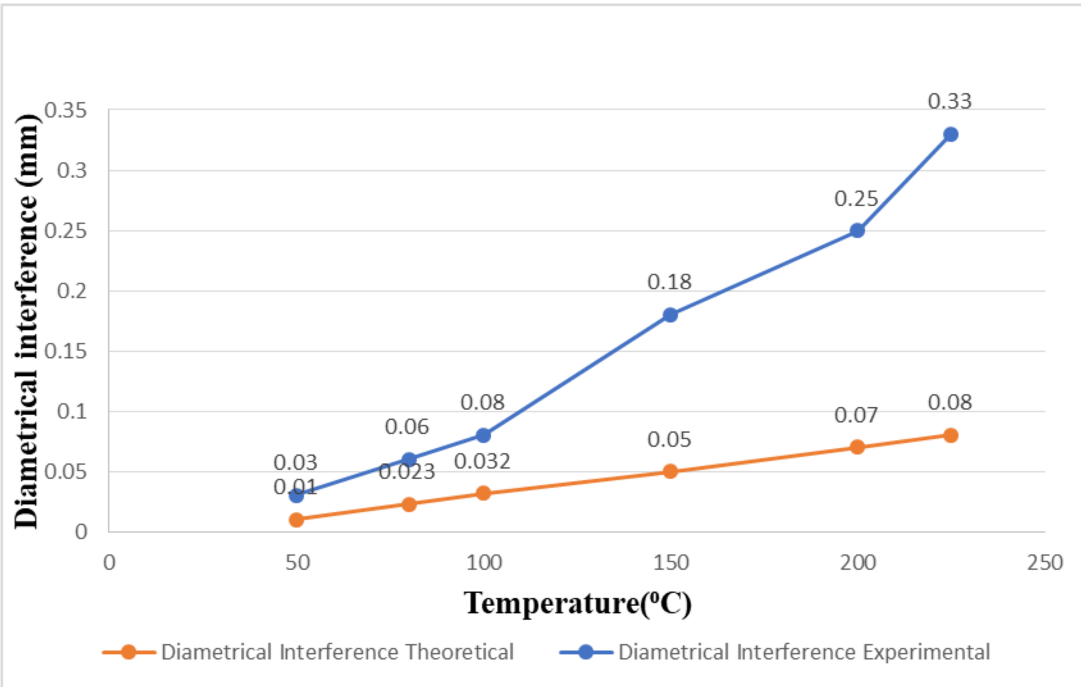

Figure 6. A comparison between theoretical and experimental measured results

Reasons for getting difference between theoretical and experimental results:

- From figure, it is observed that there is difference between theoretical and experimental expansion values, it is because of role of heating time in getting expansion.
- In experimental method, expansion obtained is more because of heating time is getting more for every time.
- More heat energy is transferred to material, so expansion is more.

Mathematical Modelling of Friction Force:

Friction or frictional force is defined as the force that resists an object's motion on a surface. The object can either be stationary or in motion relative to the surface. Friction occurs where the object is in contact with the surface. In other words, it takes place between two surfaces, and hence, is a contact force.

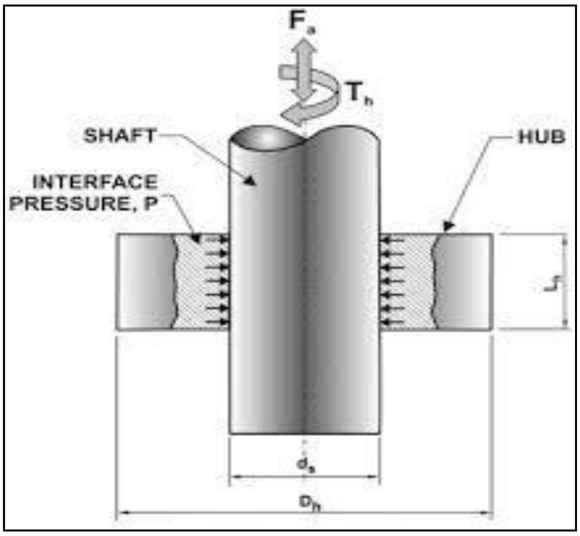

Figure 7. Schematic of Shrink fit assembly

The "coulomb friction" model is used for modelling tangential forces between contact surfaces. If tangential forces are lower than friction forces μN, they will be proportional to the relative displacement between the contact surfaces. If they are larger, the contact surfaces start to slip and the tangential forces will equal the friction forces. This condition is called as "macro-slip" model. So to avoid this phenomenon in case of rotor shaft shrink fit assembly, frictional force should be greater than the tangential force. Then there will be relative displacement between rotor and shaft.

- The contact pressure between rotor and shaft involved in interference fit is given by the Lame´s equation:

$$p = \frac{\delta}{\frac{R}{E_o}\left(\frac{R_o^2 + R^2}{R_o^2 - R^2} + \gamma_o\right) + \frac{R}{E_i}\left(\frac{R^2 + R_i^2}{R^2 - R_i^2} - \gamma_i\right)}$$

Where,

p = contact pressure between rotor and shaft during assembly (Pa)

δ = Radial interference (m)

R = Outside radius of shaft (m)

R_o = Outside radius of rotor (m)

R_i = Inside radius of shaft = zero (solid shaft)

E_o = Modulus of elasticity of rotor (Pa)

E_i = Modulus of elasticity of shaft (Pa)

γ_0 = Poisson's Ratio for rotor

γ_i = Poisson's Ratio for shaft

- Maximum frictional force developed due to contact pressure:

$F_F = p \times 2\pi \times R \times L \times \mu$

Where,

p = contact pressure (Pa)

R = Radius of shaft (m)

μ = Coefficient of friction between rotor and shaft

L = Length of contact (m)

- Tangential force given by motor :

Torque = Tangential force × radius of shaft

$T = F_T \times R$

Where,

T = Motor starting torque (Nm)

F_T = Tangential Force (N)

R = Radius of shaft (m)

If frictional force is greater than tangential force then shaft can transmit the specified power of motor and interference fit is suitable for rotor shaft assembly.

Conclusion:

- Heating from inside of the rotor bore can be a better option for heating rotor to get quicker expansion of rotor bore.
- In case of heating rotor bore, heating will be only local heating. Only required part is heated and expanded.
- This method gives possibility of avoiding cooling of assembly, so it could remove cooling operation all together.

Future Scope:

Some opportunities for future work on present dissertation work are outlined as follows:

- Heating from bore diameter can be achieved by suitably designed induction coil that fits into bore.
- Study the effect of varying the size and shape of the induction heating coil in case of external heating of the rotor.
- Add a sleeve of highly conductive material to the inner surface of the rotor so that it expands easily.

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