Dynamic and Thermodynamic analysis of Stirling cryocooler

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Introduction

The dynamic characteristics of a linear motor is effected by the moving mass and the stiffness of the spring. Hence the study of the effect of the stiffness of the spring which is an important parameter on the performance of the cryocooler is necessary. Use of wear-free, frictionless clearance seals in linearly driven miniature cryocoolers has tremendously increased the reliability and life of such units. This has been achieved by employing a non-conventional suspension system, called flexural suspension or flexure bearing. The design of the flexure bearing for a linear compressor is done by changing the various geometrical parameters.

The thermodynamics associated with the Stirling cryocooler is much associated with the performance of the regenerator and performance of the regenerator in turn is effected the length and diameter of the regenerator.

In this work dynamic characteristics are studied. Analysis on the flexure bearing to obtain a optimum design conducted to find the optimum design for the flexure bearing. The regenerator analysis was carried out in REGEN 3.2 and is optimized on the basis of the coefficient of performance by varying the diameter and length.

Dynamics

On a linear compressor many forces will be acting during its operating condition. The forces which acts are

- inertia force due to the reciprocating action
- damping force generated due to friction between the cylinder and the piston
- the force from the coil spring
- forces induced by the pressure difference between the compression and expansion of working fluid and
- electric forces resulted from the applied current.

Equation for the linear compressor can be written as follows:

\[ M \ddot{X} + c \dot{X} + k x = (P - P_a) A - B L \]  

(1)

where \( m \) is the mass of the moving assembly; \( c \) is the damping coefficient; \( k \) is the spring constant; \( P \) is the pressure inside the compressor; \( P_a \) is the buffer space pressure; \( B \) is the magnetic flux density in the air gap; \( L \) is the applied current; \( L \) is the effective coil length

The stiffness of the which is required is:

\[ k = k_{sprin} + k_{gsp} \]

(2)

\( k \) is the effective stiffness of the spring; \( k_{sprin} \) is \( n \) times the stiffness of the flexure spring; \( k_{gsp} \) is the gas spring constant

Substituting the value of stiffness in the equation (1) and solving for the maximum displacement the maximum displacement possible can be obtained.

Flexure bearing

The flexure bearing in this study is spiral arm flexure bearing and analysis is conducted on the 360, 420 and 480 degree spiral arm flexure bearing

Spiral profile which is selected is Archimedes spiral profile. Parametric Cartesian equation in polar coordinates is given by

\[ R = R_0 + R_1 \theta + R_2 \theta^2 + f [ \sin (2 \theta ) \theta ] \]

Where \( R \) is the polar distance from the center of the flexure; \( R_1 \) is the active inner radius; \( R_0 \) is the active outer radius; \( \theta \) is the relative sweep angle ratio

- outer diameter was taken to be 75mm
- the inner diameter was 6mm
- shape factor of the spiral was varied from 0.0 shape factor to 0.1

Finite element analysis was carried out for the flexure bearing and analysis was done for:

- the maximum stress developed
- axial stiffness
- radial stiffness

The material used for the analysis is SS301 having fatigue strength 870 MPa

Results from finite element analysis

The maximum stress developed, axial and the radial stiffness of the flexure bearing depends on the geometrical parameters.

variation of the maximum stress developed in the flexure bearing for various spiral angles with shape factor is shown in the figure 4

Figure4: variation of stress with shape factor and degree of spiral arm

As the shape factor increases the axial stiffness and the radial stiffness decreases. choosing high value of the shape factor is not recommended since the radial stiffness decreases which causes movement in the radial direction resulting in the friction between the cylinder walls and piston head


Regenerator

The regenerator serves as temporary heat reservoir which stores the heat and rejects the heat in the reverse direction.

The analysis on the regenerator was performed using the REGEN 3.2 software developed by National institute of standard and technology

The optimization of the design is done on basis of the coefficient of performance on changing the length and hydraulic diameter of the regenerator.

Regenerator analysis

The analysis was performed for regenerator mesh size 250 and mesh size 300. The length of the regenerator was varied from 50 mm to 90 mm and the diameter of the regenerator was varied from 4 mm to 10 mm.

Figure 6: variation of COP with length and hydraulic diameter for 250 mesh size

Figure 7: variation of COP with length and diameter for 300 mesh size

Conclusion

The dynamic characteristics of the Stirling cryocooler was studied

Based on the study conducted the optimum design for the flexure bearing was selected which was flexure bearing with 420 degree spiral arm and shape factor 0.04

Optimization of regenerator was done based on the coefficient of performance for both 250 and 300 mesh number the optimal length and diameter for the regenerator was 12 mm and 6 mm respectively.

References

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