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Fluid Structure Interaction Modeling for Geroler Motor Performance Prediction using FEA and CFD Coupled Approach

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ABSTRACT

With the ever increasing demand for developing new, sophisticated engineering products in short time, digital prototyping is a paramount tool in product design and development. In this paper, fluid structure interaction (FSI) is attempted to capture the flow ripples in a Geroler® motor. Flow ripples are spikes in outlet flow caused by sudden leakages due to localized clearance variations. If the ripples are unusually high, it may cause excessive vibrations or noise in the machine. Finite element analysis (FEA) is performed using ANSYS® to model the deformations due to pressure variations through which the gap variations are estimated. These variations are then modelled in computational fluid dynamics (CFD) analysis using PumpLinx® to predict the flow ripple. An expression-based approach is proposed to model the variable side gaps in CFD. The results are compared with experimental data and are in good agreement. The frequency is captured with 100% accuracy and the ripple amplitude with >85% accuracy.

This methodology will enable faster and more cost-effective development of new designs of Geroler motors through digital prototyping.

KEY WORDS

Geroler motor, flow ripple, FSI, tip & side gap, FEA, CFD, ANSYS, PumpLinx

1.0 INTRODUCTION

A Geroler motor is a mechanical actuator that converts hydraulic pressure and flow into torque and angular displacement (rotation). A Geroler motor is a gear motor which consists of a set of matched gears, a coupling, an output shaft and a commutator valve. Geroler motors are compact in size, low in manufacturing cost, and offer high torque capacity, making them ideally suited for low speed high torque applications. These motors can be used for many applications, including excavators, backhoe loaders, crane drives, mixer, harvesters, skid steer loader etc.

The Geroler inner rotor (star) center is eccentric to the outer ring center. The outer ting will always have one more tooth than the star. Fig.1 explains the working principle of the motor. Due to the orbital motion of the inner rotor, the pockets expand and contract based on angular position. Expanding pockets are connected to the pump side (high pressure) and contracting pockets are connected to the tank side (low pressure). The pressure difference between pockets drives the inner rotor and generates torque [1].

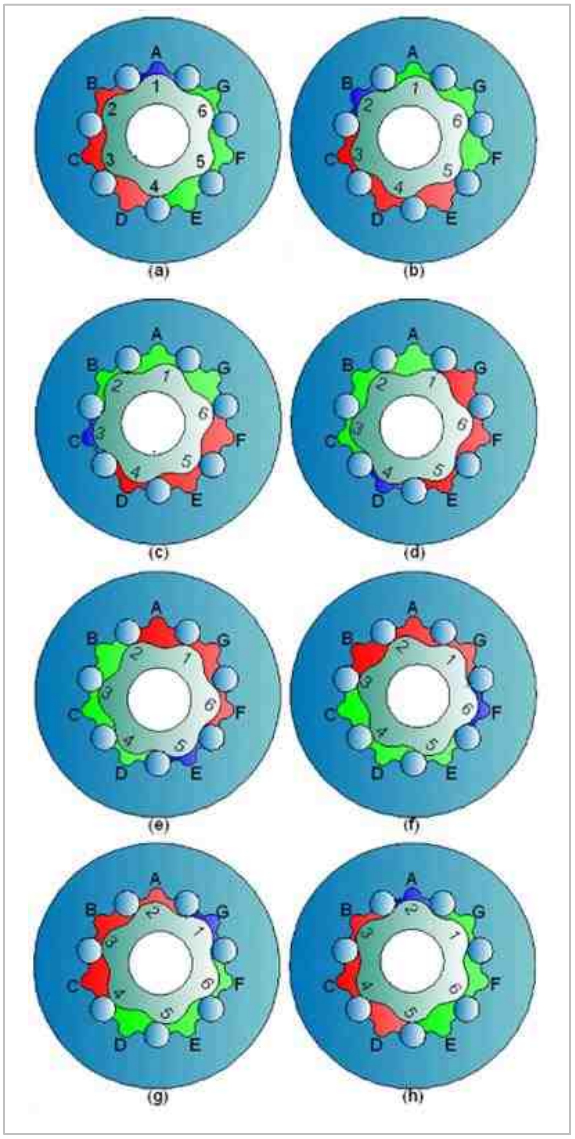

Figure 1-Geroler motor working principle

Flow ripple is one of the important performance parameters for Geroler motor qualification. The tip and side gaps in the motor need to be designed carefully, otherwise there might be high ripple in the outlet flow. These ripples may create vibration or noise in the machine. The ripple usually occurs due to sudden leakage, if the gap variations caused by localized pressures, are significant. To enable accelerated development cycles, the use of simulations is required. Current work is focused on developing a simulation methodology to predict flow ripples in the design stage. Since these gaps vary due to instantaneous pressure changes in the vicinity of solids, a multi-physics based approach is needed.

Details of the proposed simulation approach is presented in next section.

2.0 COMPUTATIONAL MODEL

A thorough study of various factors that can cause flow ripples in Geroler motors was conducted. Available test data from previous prototype tests was studied to understand the critical parameters to be modeled in simulation to ensure accuracy of predictions. From these studies, the following factors were identified for detailed investigation and improving ripple prediction accuracy:

- Instantaneous change in tip & side clearances
- Local deflections on Geroler face

These critical factors need a FSI-based approach for more realistic modeling. Numerical procedures to solve FSI problems are classified into two categories; 1. Monolithic approach, 2. Partitioned approach [2]. Monolithic approach treats both fluid and structural systems in same mathematical framework and solves them with a unified algorithm. Partitioned approach treats fluid and structure as two separate systems solved by separate algorithms. This saves efforts to develop a unified solver and allows to take advantage of validate disciplinary tools through integration [2]. A partitioned approach has been used for the current work. CFD analysis is carried out using PumpLinx, a CFD tool from Simerics Inc. [3]. CFD-predicted pressure load is then transferred to Ansys Workbench® [4] for FEA. The FEA-predicted deformations are incorporated back into the CFD model using expressions to capture the gap variations. Fig.2 shows the flow chart of the proposed approach for modeling flow ripples in Geroler motors.

In the forthcoming sub-sections, details of each step in modeling are presented.

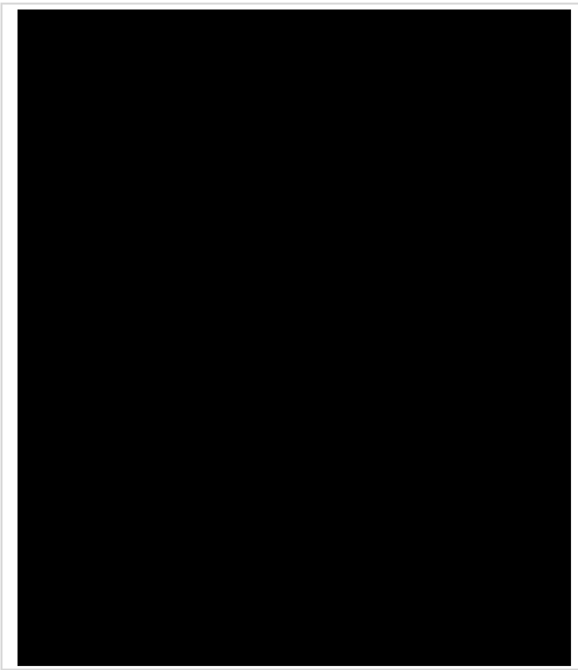

Figure 2- Flow chart of proposed multi-physics approach

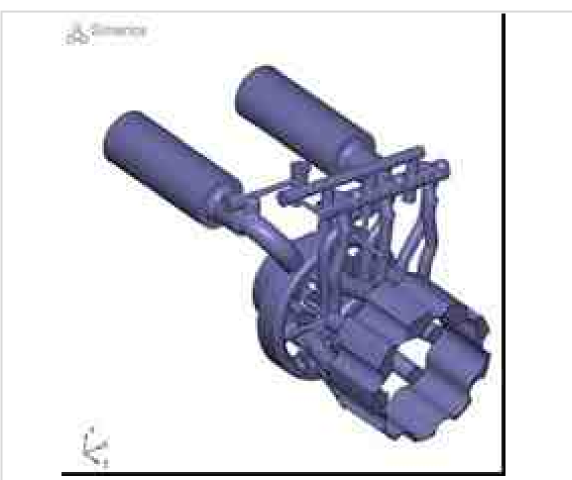

Figure 3-Geroler flow domain imported in PumpLinx

2.1 CFD model details

PumpLinx is special purpose CFD software created by Simerics Inc. and primarily used for pump/motor analyses. For setting up CFD simulation of a motor, the fluid domain of the motor, i.e., the collection of surfaces of the parts which are in direct contact with fluid are to be used for analysis. Fig.3 shows fluid domain for a Geroler motor imported in PumpLinx.

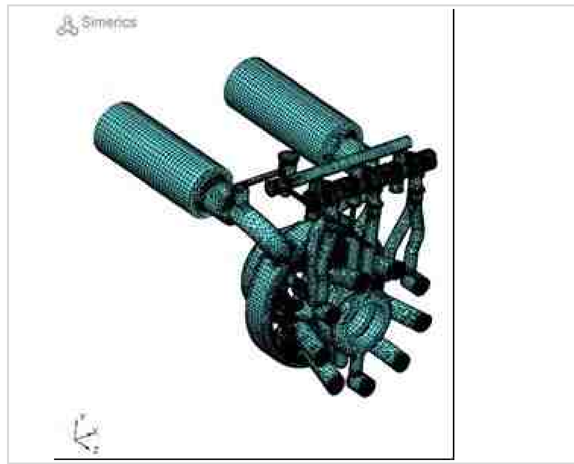

Figure 4-Non-deforming zone mesh in Geroler motor model

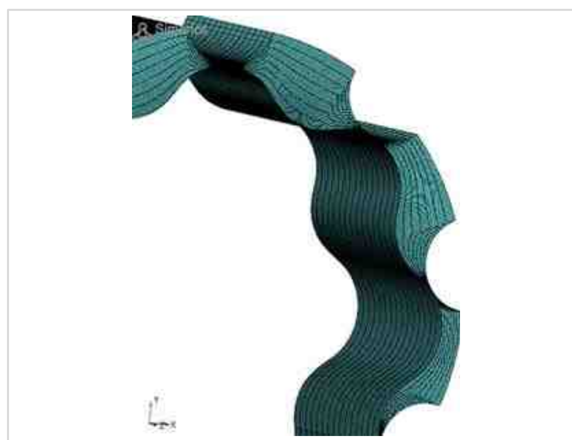

Figure 5-Structured mesh in deforming zone

Non-moving fluid volumes such as inlet and outlet passages can be meshed using either unstructured or structured algorithms in PumpLinx. Since the unstructured method uses cut-cells, the overall mesh count would not go very high depending on the parameters defined. Fig.4 shows the unstructured mesh created for inlet and outlet sections of a Geroler motor in PumpLinx.

PumpLinx offers templates for standard pump and motor types and meshing [5]. In particular, the fluid domain around the moving parts is to be segregated and templates are used for its meshing. Fig.5 shows mesh created for the Geroler motor in star-roller region.

Boundary conditions for a Geroler simulation in PumpLinx are shown in Table 1. Since a Geroler motor is a positive displacement device, the volumetric flow rate per revolution depends on the effective swept volume per revolution and effective leakages during operation. The pressures on inlet and outlet boundaries are dictated by adjacent system pressures and are input for the simulation. Boundary motion specification is handled with templates in PumpLinx®.

Table 1-Boundary conditions for Geroler motor

Boundary name	Type
Motor inlet	Specified pressure inlet
Motor outlet	Specified pressure outlet
Star (Inner Rotor)	Specified boundary motion

A two equation, standard k-epsilon turbulence model is used in PumpLinx. This approach has been validated in literature [6,7,8] for pumps and motors CFD modeling. Properties of the working fluid are mentioned in Table 2 below.

Table 2-Oil properties

Property	Value	Unit
Density	861	kg/m^3
Viscosity	59.3	cSt
Bulk Modulus	1.5E+9	Pa

This completes the Geroler motor specific settings in PumpLinx.

2.2 FEA model details

It is very important to incorporate the effect of change in clearances due to structural deformation. Change in clearance due to structural deformation will impact the leakages, which in turn will affect the ripple phenomenon. Effect of structural deformation is studied by performing FEA of motor assembly using ANSYS 16 workbench®. Pressure loads for structural study is imported from preliminary CFD study without considering the effect of structural deformation. Fig.6 shows loads applied and Fig.7 shows constraints applied on the FEA model.

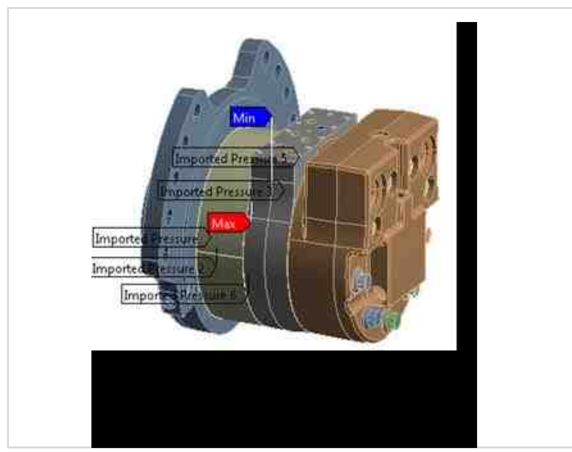

Figure 6-CFD imported loads in FEA model

2.3 Modeling variable tip and side gaps through expressions

Fig.8 depicts inlet and outlet pressure distributions on star and housing surfaces at any given instance during operation. As the high- and low-pressure distribution on star and housing surfaces are spatially separate, we can assume linear surface deformations. This is depicted in right half of Fig.8. As the pocket pressure transition has a relationship with star rotation, the variable gaps can be modelled by rotating the deformed surfaces at the orbital motion speed.

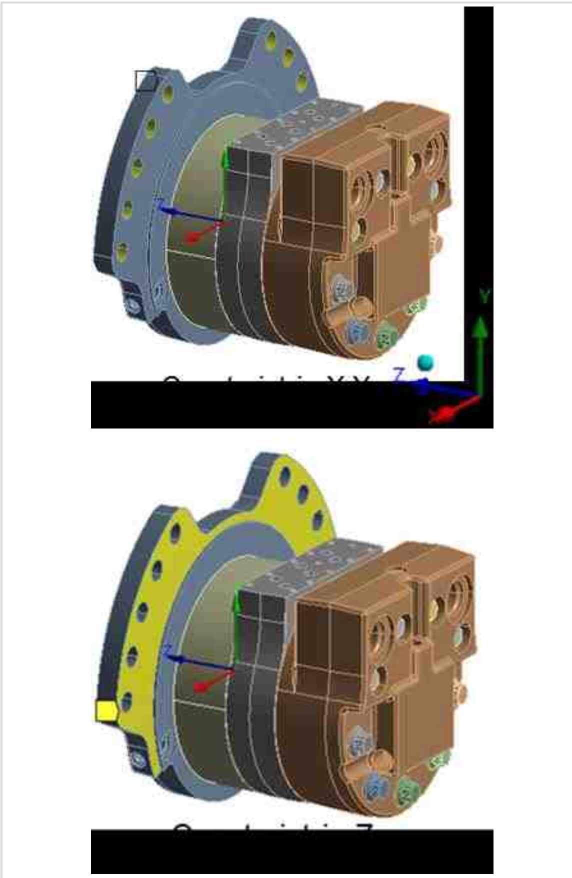

Figure 7-Constraints applied on FEA model

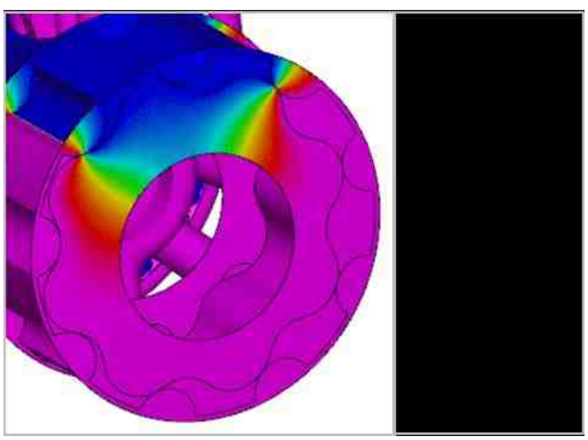

Figure 8-Variable side gap modeling through expressions

The side gap is modeled as a thin annular disk of thickness (axial coordinate), varying as a function of radial and angular coordinates. The minimum and maximum clearance (thickness of disk) can be adjusted to match with FEA predicted minimum and maximum gaps by choosing the appropriate value for angle of tilt in the expression.

Flow rates at the outlet of the motor are monitored in the CFD simulation with deformed surfaces to predict the flow ripple.

This completes the description of proposed method for FSI modeling of Geroler motor.

3.0 RESULTS AND VALIDATION OF APPROACH

This section describes application of the proposed methodology to low temperature cases for Geroler motors. The flow chart of the methodology is presented in Fig.2. Flow domain with nominal clearances is used for initial CFD analysis in PumpLinx. Pressure distribution from the nominal CFD model is mapped onto the FEA Model. Fig.9 shows a comparison of the CFD pressure with pressure mapped on to FEA model for rotor surface.

Structural FEA is performed to evaluate the deformation based on mapped CFD pressure. Fig.10 shows the relative axial and radial deformations of adjacent components as well as proximity with respect to each other.

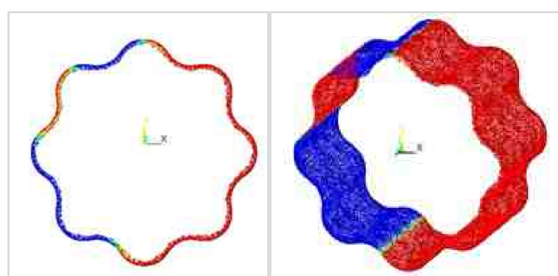

Figure 9-Mapped CFD pressure profile

Relative deformations are exported and used as input by the CFD model to account for the effect of change in clearance on flow ripple. These deformations are incorporated in the CFD model by adjusting tilt angle in the expression such that minimum and maximum clearance match FEA predictions. Flow rate prediction from the CFD model are compared against test flow rates in Fig.11. Simulation prediction trends are in good agreement with test trends. The approach is validated with test results with approximately 85% accuracy for flow ripple magnitude and 100% accuracy for ripple frequencies.

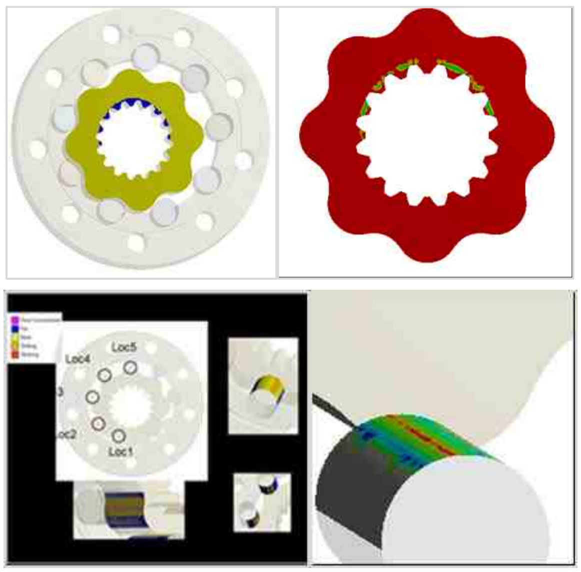

Figure 10-Axial and radial deformations from FEA

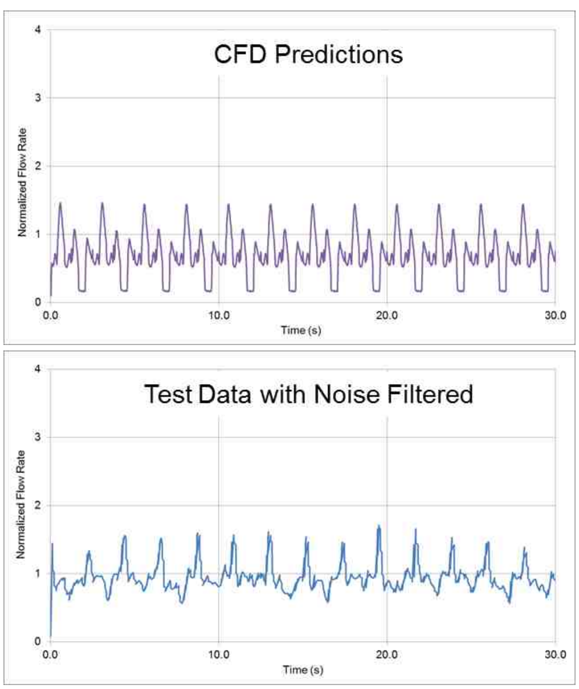

Figure 11-Simulation results validation with test data

4.0 CONCLUSION

In this work, a CFD-FEA, 1-way coupled approach is proposed to predict flow ripples in Geroler motor. The proposed analysis method involves a preliminary CFD simulation with nominal clearances, followed by FEA to predict structural deformations and finally incorporating the variable clearances back in CFD simulation. This approach is validated with test results for a Georler motor with approximately 85% accuracy for flow ripple magnitude and 100% for ripple frequencies. This methodology is being leveraged for design and optimization of Geroler motors to reduce design cycle times and cost. Considering the success on one product line, this methodology can be appropriately extended to other pump and motor families.

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REFERENCES

[1] Vickers industrial hydraulics manual, chapter 7,page no 161

[2] Hou G, Wang J, Layton A, 2012, “Numerical methods for fluid–structure interaction—a review”, Commun. Comput. Phys. Vol 12, No 2, pp.337–377

[3] PumpLinx 4.1.2 Theory Guide – CFD model.

[4] ANSYS 16 User Manual – Structural mechanics.

[5] H Ding, X J Lu and B Jiang, 2012, “A CFD model for orbital gerotor motor”, IOP Conf. Series: Earth and Environmental Science, Vol 15, part 6.

[6] S Salutagi et. al, 2015, “Axial Piston Pump Performance Prediction using 3D CFD Simulation”, Fluid Power Innovation & Research Conference 2015.

[7] H Ding, H Gao, 2014, “3-D Transient CFD Model For A Rolling Piston Compressor With A Dynamic Reed Valve”, International Compressor Engineering Conference 2014, Purdue e-Pubs.

[8] X Sang, X Zhou, X Liu, 2015, “Numerical Simulation of an Inner Engaging Gerotor Based on the Optimization of Inlet and Outlet Cavities”, 5th International Conference on Advanced Design and Manufacturing Engineering.

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