Design, Development and Experimental Investigation of Epitrochoid Internal Lobe Pump

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Abstract— The trochoidal drives are widely used in the industry for the constant flow requirements. The design of the lobe profile for positive displacement internal lobe pump (Gerotor) requires MATLAB, Auto-CAD, Solidworks and MasterCAM software. The main objective behind this development of epitrochoid lobe rotor is to increase the flow as well as decrease in noise level (smooth operation). This epitrochoid curve requires set of parametric equations, which is solved with the help of MATLAB. The epitrochoid lobe profile requires modelling for the manufacturing purpose, which requires modelling as well as manufacturing software like AutoCAD, Solidworks, MasterCAM and CNC for code generating. At the last the developed profile has been manufactured and tested to check its technical feasibility. The test results are examined and compared with existing model of lob rotor.

Key words: Trochoidal gear drive, Gerotor pump, Pump design, and CAD/CAM

I. INTRODUCTION

The mechanism of Ge-rotor first of all realized by Myron F. Hill in 1906, which describes internal trochoidal gearing. The name Ge-Rotor is derived from the phase Generated Rotor as profile of inner gear is generated from the external profile. Ge-rotor is used where gear pumps with external gearing are present and, also, it can be used where gear Pumps with internal or fixed displacement vane pump are present for cooling and lubricating systems for transfer of liquids. Ge-rotor pumps belong to the group of rotational pumps and they have great advantages comparing other types of rotational pumps. Some of the advantages are simple constructions and variety of applications. Due to specific geometry of gear profiles, continuous contacts of all teeth are provided in exploitation that obtains the necessary separation between the low and high pressure zones. During the operation, teeth of the pump rotor act as pistons while chambers (the space between profiles of inner and gears) correspond to cylinders. The lobes of the male and female rotors are designed as a conjugate pair with law of gearing. In design of Ge rotor pumps, the major challenges are related to the fault free design and fabrication of the rotor profile.

Giovanni Bonandrini, et al. [1] has used differential geometry to generate the conjugate surfaces of epitrochoidal gearing. Giovanni Mimmi, et al. [2] has used an original profile for internal rotary pumps, which has many advantages in comparison of common epitrochoidal design. Yii- Wen Hwang, et al [3] has generated profile of lobe rotor and the mathematical model of the internal Cycloidal gear with tooth difference is generated by theory of gearing.

Scope of this paper is to develop a profile for inner rotor and outer rotor from parametric equations of epitrochoid curve in MATLAB software for the company 'Pumpsquare Systems LLP'. From generated profile drawings and solid models are to be developed. The objective is also to manufacture developed model using CAM technology. The paper also involves testing of manufactured model for comparing it with existing model.

There are two types of lobe pumps. One is external lobe pump and second one is internal lobe pump. Presently the company uses an excel program for lobe profile generation which results in unsmooth motion of rotors and requires an additional grinding process. The company needs to eliminate this extra process and wants to develop a lobe profile with enhanced capability of the output. Now a day's many software's and programming languages are available for such type of requirements. Here the effort has been made to develop a program which fulfills the requirements of the industry. MATLAB 2012 is used to develop a program for generating optimized epitrochoidal lobe rotor profile.

II. EPITROCHOIDAL LOBE PROFILE ROTOR

An epitrochoid is defined as a path, which is traced by a point lying inside the rolling circle that rotates outside of a base circle circumference. As the classical epitrochoidal pumps, the assembly of the considered machine is constituted by an inner rotor which can be assumed as a pinion, since it transmits the motion to the outer rotor.

A. Mathematical Model of Epitrochoid Lobe Profile

One method for generating the internal cycloidal gear is shown in Figure. 1. Circles 1 and 2 are in internal tangency, and their radius is radii ρ1 and ρ2 separately. Point I is the instantaneous center of rotation. When circle 1 rotates counterclockwise around the circumference of circle 2 in a pure rolling motion, the eccentric throw r is the distance between point p and the center of circle 1, and point p generates an extended epicycloid path. This path could be the center of rollers and then the profile of inner cycloidal rotor (or cycloidal wheel) would be generated by the inner envelope methods.

The ratio of the inner rotor's rotation angle to that of the outer rotor is inversely proportional to the ratio of the tooth number. Therefore, the relationship between rotation angle φ_2 and φ_1 is represented as follows:

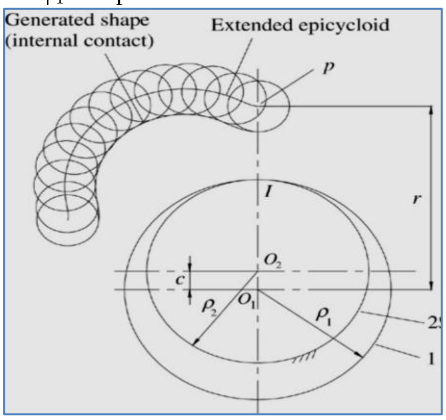

Fig. 1 Generation of the extended epicycloidal curve

Inner rotor can be determined by following co-ordinates transformation and equations.

Inner Rotor:

$$t_2 / t_1 = N/(N-m) \ldots\ldots\ldots\ldots \quad (2.1)$$

Where N is the tooth number of the outer rotor, m is the tooth number difference between the inner rotor and the outer rotor. Thus, the tooth number of the inner rotor is N-m.

$$\lambda = a/(e * N) \ldots\ldots\ldots\ldots \quad (2.2)$$

$$\alpha = a*\tan(\sin(t_1)/(\lambda - \cos(t_1)) \ldots\ldots\ldots\ldots \quad (2.3)$$

The equation of the inner rotor can be determined by the following coordinate transformation:

$$r_1(\alpha, t_1) = M_{21}(t_1)*r_1(\alpha) \ldots\ldots\ldots\ldots \quad (2.4)$$

Where

$$M_{21} = \begin{bmatrix} \cos(t_1 - t_2) & -\sin(t_1 - t_2) & -e*\sin(t_2) \\ \sin(t_1 - t_2) & \cos(t_1 - t_2) & -e*\cos(t_2) \\ 0 & 0 & 1 \end{bmatrix} \quad (2.5)$$

$$r_1(\alpha) = \begin{bmatrix} R\sin\alpha \\ r - R\cos\alpha \\ 1 \end{bmatrix} \ldots\ldots\ldots\ldots \quad (2.6)$$

Now equation 5 & 6 to be used in equation 4

$$r_2(\alpha, t_1) = \begin{bmatrix} -a\sin(t_1 - t_2) + R\sin(\alpha + t_1 - t_2) - e*\sin t_2 \\ a\cos(t_1 - t_2) - R\cos((\alpha + t_1 - t_2) - e*\cos t_2 \\ 1 \end{bmatrix} \quad (2.7)$$

$$f_1(\alpha, t_1) = (dr_2/(d\alpha)*k)*dr_2/dt_1 = 0 \ldots\ldots\ldots\ldots \quad (2.8)$$

Where “k” is the unit vector in z direction.

Above equation determine the generated tooth profile of inner rotor.

Outer Rotor:

$$\Phi 2/\varphi 1 = N/(N-1) \ldots\ldots\ldots\ldots \quad (2.9)$$

$$rb(\alpha, t1, \varphi 1) = \begin{bmatrix} -a\sin(\varphi_1 - \varphi_2 + t_1 - t_2) + R\sin(\varphi_1 - \varphi_2 + t_1 - t_2) - e[\sin\varphi_2 - \sin(\varphi_1 - \varphi_2 - t_2)] \\ a\cos(\varphi_1 - \varphi_2 + t_1 - t_2) - R\cos(\varphi_1 - \varphi_2 + t_1 - t_2) - e[\cos\varphi 2 - \cos(\varphi_1 - \varphi_2 - t_2)] \\ 1 \end{bmatrix} \quad (2.10)$$

$$f_2(\alpha, t_1, \varphi_1) = (dr_b/(d\,t_1)*k)*dr_b/d\varphi_1 = 0 \ldots\ldots\ldots\ldots \quad (2.11)$$

Where “k” is the unit vector in z direction

Simultaneous consideration of Eqs. (2.7), (2.9) and (2.11) then allows determination of the generated shape between the outer rotor arc teeth.

III. DEVELOPMENT OF NEW LOBE ROTOR

For developing the lobe rotor required input data is selected as shown in table 1.

Input Data	Value
No. of lobe for outer rotor, N	5
Central distance between circles, a	40 mm
Radius of curvature, R	20 mm
Eccentricity, e	4.813 mm

Table 1: Input Data for Lobe Profile Generation

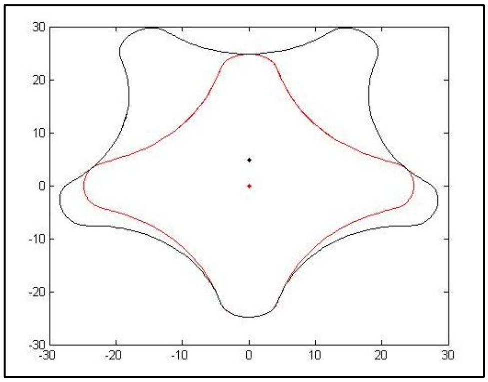

Fig. 2 epitrochoidal lobe profile

A MATLAB program is generated which plots the epitrochoidal rotor profile shown in fig. 2 and stores the co-ordinates of the points in a variable. This data is exported in to an excel sheet and saved in .csv format. This type of format is used to store different data column wise. This column wise data is copied to a notepad file which is saved as .scr file. It is the format of a script file that can be ran in AutoCAD for generating drawing files. Method for running script file is shown in fig. 3.

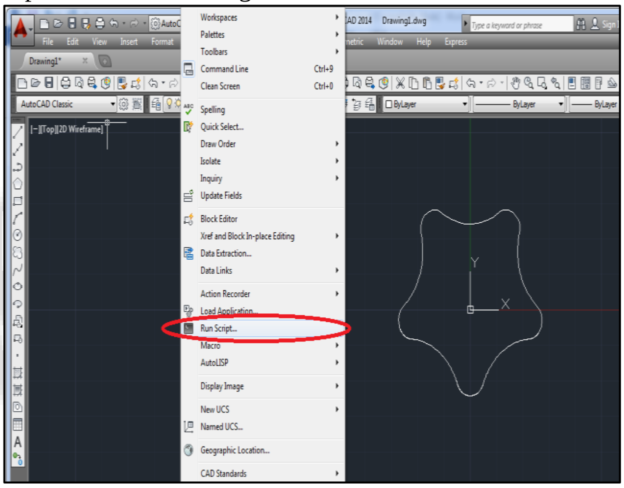

Fig. 3 outer rotor in Auto-CAD

Fig. 4 outer rotor

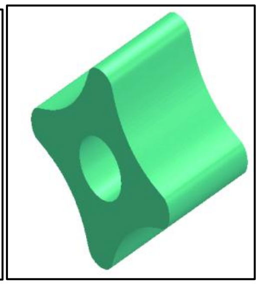

Fig.5 inner rotor

The AutoCAD drawing file is directly imported in to Solidworks as a sketch which is extruded to generate 3D solid model of the developed lobe rotor. Solid models inner and outer rotor is shown in figure 4 and figure 5.

Now, the AutoCAD file can also be imported in MasterCAM software which is the software that generates CNC codes from 3D model. After some modifications CNC codes are generated for developed rotors. This codes are exported to a vertical milling center at the company to manufacture developed lobe rotors. The specifications of the VMC machine is shown in table 2. Manufactured lobe rotors are shown fig. 6.

Fig. 6: manufactured lobe rotoros

Power supply	415 ±10, 3 phase, 50 Hz.
Drive motor	1.5-2.0 HP&900-1400 rpm.
Temperature	10 to 45°c.
Spindle motor	5-10 KW.
Cutting feed control	Hydraulic.
Cutting speed range	20 – 80 m / min.
Feed length	0 – 400 mm.

Table 2: VMC Machine Specification

IV. TESTING AND RESULTS:

Developed rotors are assembled into internal lobe pump which was subjected to performance measurement test at the company. An oil with viscosity of 40cst is used as working fluid. The pump is kept running for 2 hours and then readings are taken for three different pressure 0 kg/cm^2, 2 kg/cm^2 and 4 kg/cm^2. The results of the test for existing and developed model are shown in fig. 7, 8 & 9.

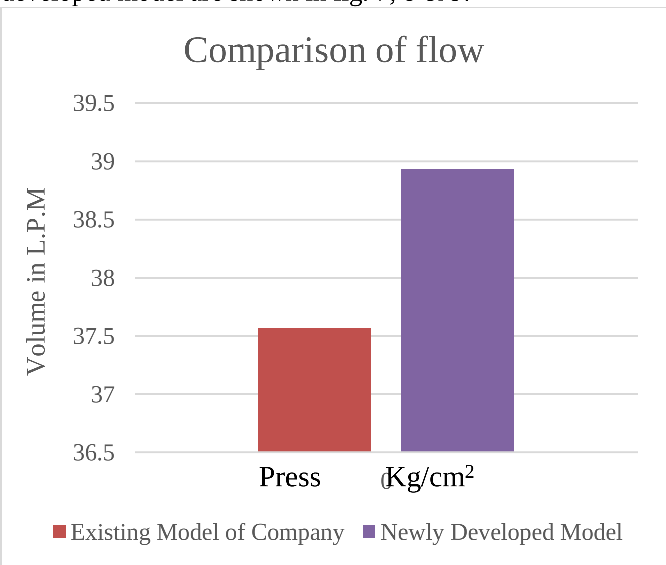

Fig. 7 Comparison of flow at 0 Kg/cm^2 Pressure

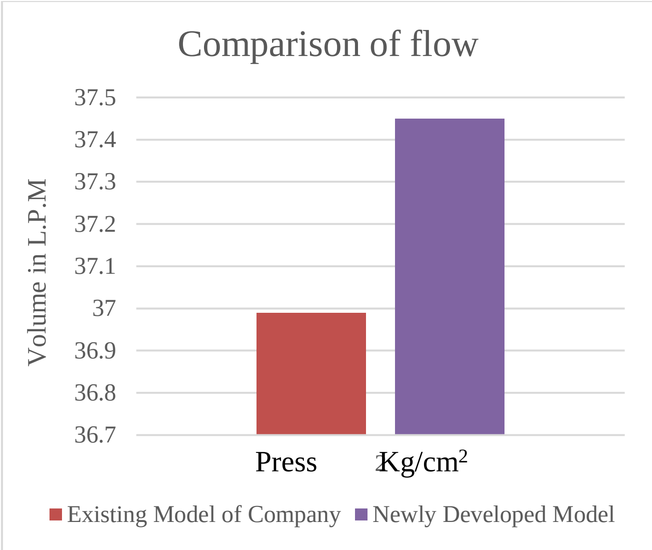

Fig. 8 Comparison of flow at 2 Kg/cm^2 Pressure

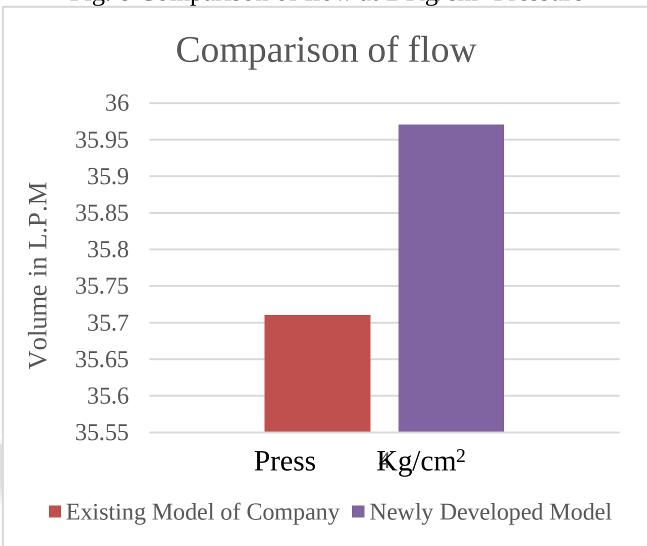

Fig. 9 Comparison of flow at 4 Kg/cm^2 Pressure

From the results shown in above figures 7, 8 & 9, we can see that developed rotors gives better flow output compared to existing one.

V. CONCLUSION

At the end of the effort done, a process for developing epitrochoidal lobe rotor is derived. A program in MATLAB is created that plots and stores data of generated profile. Drawings and 3D models of rotors are generated using CAD softwares. CNC codes are generated automatically and rotors are manufactured on VMC. Validation of effort is done through performance test and comparing results of existing and developed model. The tests validate development of rotor design with more output capacity.

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