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A REVIEW ON THEORETICAL ANALYSIS AND DESIGN OF A VARIABLE DELIVERY EXTERNAL GEAR PUMP FOR LOW AND MEDIUM PRESSURE APPLICATIONS

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ABSTRACT

The objective of the review paper is to described a unique design concept that was capable of electronically controlling the flow which delivered by an external gear pump(EGP). The principal used for varying the flow realize on the variable timing concept which was previously demonstrated by the authors team for EGP's operating at the high pressure(p< 100 p) but that concept was permits flow to vary within a specified ranges and they didn't introduce the additional source of power loss. In this review paper above proposition had been applied to invent a design for variable delivery EGP for low pressure (p<30) and medium pressure, suitable for direct electric actuation. External gear pump are most hydraulic pump and in low pressure ranges due to their long high efficiency and low cost. The detailed analysis concerning the relationship between the electrically commanded position for flow varying element and theoretically delivered by the pump also presented the review paper details design the concept of the proposed variable flow from also described multioptimization approach used for sizing gears and variation mechanism.

***Keywords**: Low and Medium Pressure External Gear Pump (EGP), Hydraulic pump.*

I. INTRODUCTION

External gear pumps are widely used in several fluid power application due to their reliability low cost, high compactness, good efficiency, good tolerance to contaminants and cavitation. External gear pumps also have many advantages over other positive displacement units, high reliability make them successful for number of applications fluid power in automotive lubrication and fuel injection system. However EGP's inherently fixed displacement units there are many fig. in literature which discuss the energy advantage given by variable ones significant is the review work given by Rundo,[1] for the case of pumps used in automotive lubrication system.

In literature one can find several solution to vary the displacement of the EGP through radial motion of gears some significant example Are available on reference[2,3]. This is solution announces challenges related to the actuation mechanism which meets pressure loading of application thus this is solution found commercial success for low pressure application as register in [4,5]. Recently one author team has joined this research effort to getting solution for variable displacement EGPs as part of this effort in 2014 the principal of vg-EGP was formulated [6]. On the basis of that a variable gear pump was designated for high pressure application in a more depth theoretical analysis of the torque and flow reduction using the variable timing concept presented in[8]. In this work the design of VD-EGP have been revisited by the author and he derived new implementation of variable timing concept which is more suitable for low pressure and low cost at EGP operating at low delivery pressure the methodology for design is depend on numerical optimization as documented in [6]; however in these work author propose a new design offers and internal pressure compensation which allowable for a minimum actuation force required for flow variable mechanism which is enable a direct electric control for VD-EGP. This solution was first presented in 2017 ASME conference[9].

The constitution of the review paper is as follow in section 2.1, aBrief description of the variable timing concept is given the design approach and all the assumptions are given in section 2.2 and in section 2.3 the theoretical formulation used to drive the analytical expression of instantaneous flow rate is discuss. Section 2.4 gear profile design and shows the refinement done to the optimization process. Section 2.5variation of flow rate and variable delivery constant, section 2.6 result of experiment and feasibility and of the design is verified.

II. METHADOLOGY

2.1Brief description about vd-egm concept

The VD-EGM concept is mainly base on a variable timing concept which is realized by the connection of each tooth space volume(TSV) with the inner and outer environment the detail information about thus concept is available in [6], but it will be summarized this will be in section for sake of completeness as the gear rotates then each displacement chamber switches its connection form outlet port to the inlet port of precise point which is determined by position lateral groove.

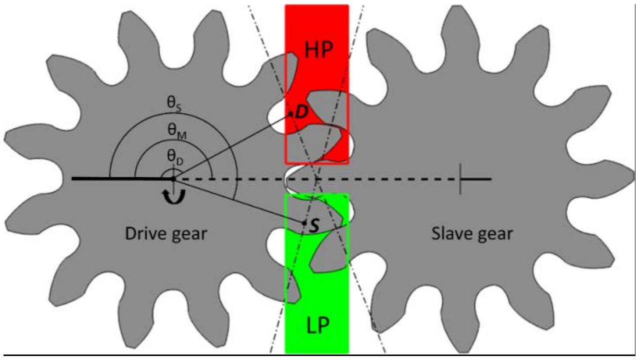


Fig2.1: VD 0EGP Concept of Lateral groove Position

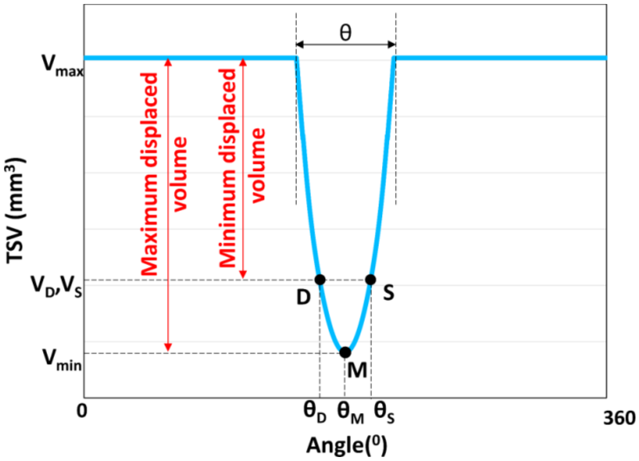


Fig2.2: Operation of VD-EGP with respect to One TSP

Basicallyfig 1 and 2 illustrate this concept of variable timing. In particular fig2.shows the volume display by 1 TSP, if the groves are positioned so as torealize the commutation point at the position of minimum TSP in that case maximum amount of flow is display by the unit. However by translating the grooves of fig 1, computation point is varied and effective volume is get decrease which is transferred by the displacement chamber to reduce the cavitation the author have preferred the strategy of the communication to inlet ,by keeping each TSP for a longer time an after a minimum volume initiatively, this reduces the shaft torque require since pressurized TSP after the minimum value point generates a torque which leads to the shaft rotation it also noted that this variable timing concept is more effective in between the angular points. The delivery flow rate is minimum when the grooves are at the point S and maximize where at M. then ratio of minimum to maximum flow rate which is as denoted by β given by

β = Vs/Vm

2.2 Design of the vd-egp

The presented design for the low pressure VD-EGP aims at limiting the modifications as much as possible with respect to the basic EGP design. Typically, an EGP used for low pressure applications does not use axial gap compensation. This means that the floating elements used to control the clearance at the gears lateral sides (pressure plates or lateral bushings) are not present. Therefore, the lateral grooves realizing the lateral connections of the TSV's can be implemented directly on the end covers of the EGP. The position of the lateral grooves is controlled by a "slider" (similar to the one used in [11]) which is integrated into the end cover of the EGP. Further, it is assumed that there will be no significant axial imbalances if only one slider is used for a pump operating at relatively low pressures. Thus, only one slider element is used for regulating the pump delivery flow. Fig 3

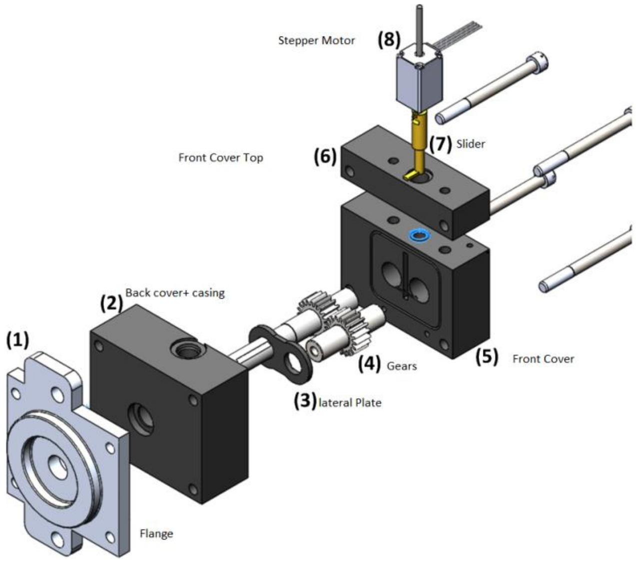


Fig2.3: Exploded view

2.3 Slider implementation and force balance:

The design of the slider is done with the idea of balancing all the pressure forces acting on it, so that the force required from the actuation mechanism is always minimum. The principle of force balance of the slider is shown in action in the main idea is to compensate the forces along the axis of the slider motion flow variation is. In order to have the separation of pressures shown in seals must be used. This requirement forces to fit the slider in the front cover. However, to still serve the function of separating the high and low pressure regions of the TSVs, the bottom of the slider is extended to align with the lateral surfaces of the gears.

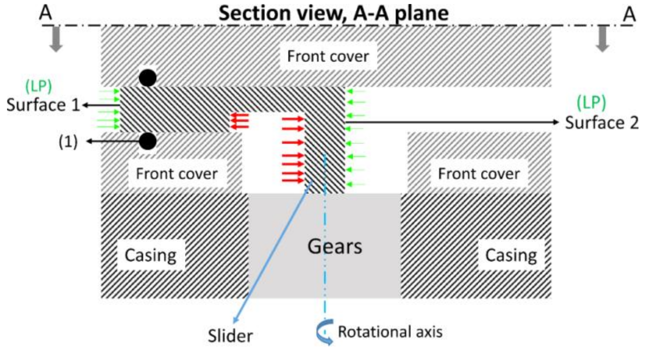


Fig 2.4: Design principle of slider, (1) O-ring seal for maintaining pressures.[16]

The value of design parameter of R-slider is as shown in fig 2.3 which is available in commercial o- ring size, therefore there will be small non zero force acting on a slider in the implemented prototype also there is some friction between o- ring and slider. To balance slider the total amount of force acting on it must be zero that means pressure force acting on it must be zero the main advantage of having a balance slider which required small actuation force to change displacement to permit direct electric actuation to use a stepper motor. To balance the forces the net areas to expose to delivery and succession pressure must be zero that is-
$A4=A3$ (1)

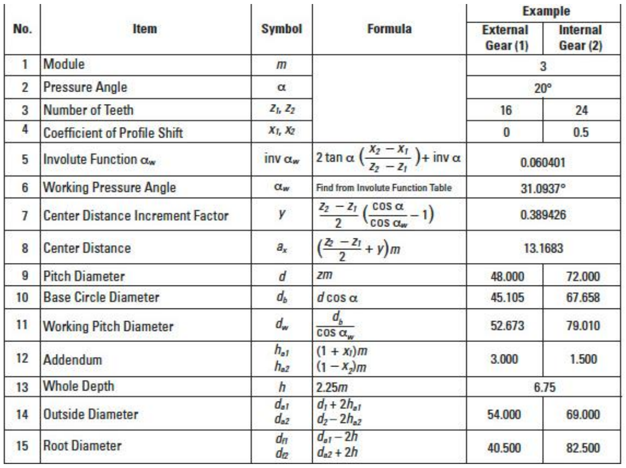
Bysubtracting shaded area from the rectangular surface as shown in fig 2.3 gives A4.
The area circular segment used for these is given by A4=WL- area of shaded region (2)
Therefore
$A4= WL- (r^2 \sin^{-1} w/2r- w/2*(r^2-w^2/4)^{1/2}$(3)
Hence, equation (1) reduce to
$\therefore WL-r^2 \sin-1 (w/2r) + w/2 *(r2 - w^2 /4)^{1/2} +\pi r^2 = \pi R^2$(4)
$\Rightarrow A2 = A1$ (5)
Equation 4 shows that area exposed to succession pressure are automatically balanced.

To solve for our design parameter of slider further restriction are imposed on slider design the values of W and H are depend on groove design assuming the best value ‘r’, the other parameters were found keeping the below limitations in mind.
Aspectratio $L/H <1$ (6)

The value of radius R a slider is determine from standard o ring size available in market geometric constraint
$2*r<W$ (7)

III. GEAR PROFILE DESIGN

Maximize the range of flow variation is the biggest challenge in implementing the variable timing concept which can be find out by the location of D and S with respect to the M on TSV fig 2. While, designing the gear profile must be design with the intention of moving D and S as far as possible from M which requires careful analysis of VD-EGP from the prospective of gear profile design. The authorhave a use technique which wherever developed for past optimization of EGP to formulate work for suitable for the low pressure of EGP’s.the performance of regular EGP has significantly influence by the profile shift factor hence this work include effect of shift factor on the flow variable range which taken account in the optimization frame work.



No.	Item	Symbol	Formula	Example	
				External Gear (1)	Internal Gear (2)
1	Module	m		3	
2	Pressure Angle	α		20°	
3	Number of Teeth	z_1, z_2		16	24
4	Coefficient of Profile Shift	x_1, x_2		0	0.5
5	Involute Function α_w	inv α_w	$2\tan\alpha\left(\frac{x_2-x_1}{z_2-z_1}\right)+\text{inv}\,\alpha$	0.060401	
6	Working Pressure Angle	α_w	Find from Involute Function Table	31.0937°	
7	Center Distance Increment Factor	y	$\frac{z_2-z_1}{2}\left(\frac{\cos\alpha}{\cos\alpha_w}-1\right)$	0.389426	
8	Center Distance	a_x	$\left(\frac{z_2-z_1}{2}+y\right)m$	13.1683	
9	Pitch Diameter	d	zm	48.000	72.000
10	Base Circle Diameter	d_b	$d\cos\alpha$	45.105	67.658
11	Working Pitch Diameter	d_w	$\frac{d_b}{\cos\alpha_w}$	52.673	79.010
12	Addendum	h_{a1} h_{a2}	$(1+x_1)m$ $(1-x_2)m$	3.000	1.500
13	Whole Depth	h	$2.25m$	6.75	
14	Outside Diameter	d_{a1} d_{a2}	d_1+2h_{a1} d_2-2h_{a2}	54.000	69.000
15	Root Diameter	d_{f1} d_{f2}	$d_{a1}-2h$ $d_{a2}+2h$	40.500	82.500

Fig 3.1: Cutting process parameter

The optimization problem is can be solved by adopting approach which is similar to the one out line in [6].
The objective function is summarized in the section there are two level of optimization strategy due to the different nature of OFs.The first level deals with the design of the gears, and is focused on generating feasible gear designs with the best value of OF1. For each feasible design generated in level 1, a sub-level optimization of the grooves is carried out in level 2 to determine the remaining OFs. As mentioned that the remaining OFS are depends highly on connection realize between gear and lateral groove and fluid properties. Two level of optimization are illustrated in Fig. (6) level two optimization process influence by the design of slider the sealing action performed buy foot of slider. HYGESIM is the tool

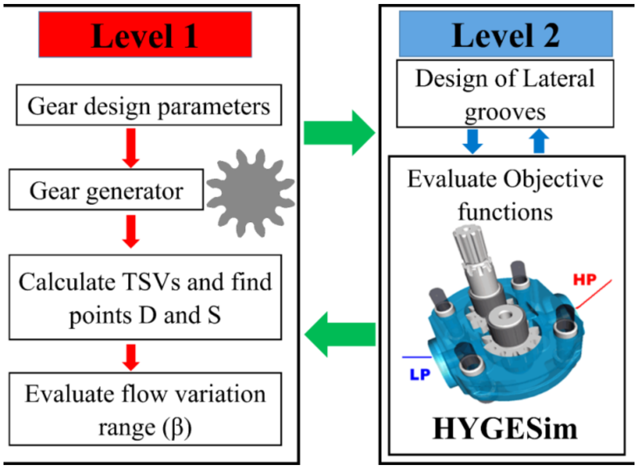


Fig 3.2: Illustration of the multilevel and different objective optimization approach

which is used to make level to make grove optimization simpler than level work this tool has adopt lumped parameter approached to find out the important performance characteristic such as volumetric efficiency and cavitation, gear micro-motion and flow ripple.

3.1objectivefunction:

3.1.1Maximize flow variation range:

As described in[6], the flow variation range for duel flank gear operation can evaluated for drive by slave TSP as

$$Bnet = \beta drive + \beta slave/\ 2 = VS1 + VS2/\ 2Vm \qquad (8)$$

$\Rightarrow OF1 = 1-\beta net(9)$

3.1.2Minimize local cavitation:

$OF4 = \int P_{T\,SV}\, d\theta\ \forall\ P_{T\,SV} < Psat(10)$

To achieve designs with lower cavitation effects, the TSV pressure must be kept above the saturation pressure of the fluid for large intervals.

3.1.3Minimize delivery flow ripple:

The final design should aim to minimize the fluctuations in the delivery flow (ripple):

$OF2 = {}^{N}\sum_{k=1} \Pi{*}k \qquad (11)$

3.1.4 Minimize Pressure peaks:

Reducing the pressure peaks while pumping is necessary for good working life of the EGP.

$OF3 = (P_{TSV,max} - P_{D,avg})/(P_{D,avg}) \qquad (12)$

Where, PT_{SV},max is the peak pressure in the TSV during the meshing process and P_{Davg} is the mean delivery pressure.

3.1.5 Maximize volumetric efficiency(Ƞ)

$OF5 = \eta = (Q_{avg}/w{*}V_d) \qquad (13)$

3.1.6 Volumetric efficiency is the ratio of actual flow rate of the pump to the
Theoretical flow rate of the pump. This is expressed as follows:
Volumetric efficiency =
(Actual flow rate of the pump /Theoretical flow rate of the pump)

Volumetric efficiency (Ƞ):- indicates the amount of leakage that takes place within the pump. This is due to manufacture tolerances and flexing of the pump casing under designed pressure operating conditions.
For gear pumps,(Ƞ)
= 80%–90%.

$OF5 = \eta = Qavg/(w{*}V_d) \qquad (13)$

The first objective OF1 relates to the flow variation range which depends only on the gear geometry while the other objectives from OF2−OF5 deal with the overall performance of the pump which depends on the gears and the other components in the pump (lateral grooves). Hence these objectives are dealt with in level 2 of the optimization process, while level 1 deals with OF1.

The duplicate design which are arising from the scaling of design can be avoid by scaling gear design by operating distance.Thegear design scaled by also by module.we can avoid scaling by using optimization algorithm to explore a large design space the other restriction imposed on the optimization relates to the avoiding and pointed and keeping desirable teeth to the root clearance, contact ratio, interference aspect ratio.

3.2 optimization result

The optimization was run about 70 generation of generic algorithm for nearer 5,500 designs.as declared previously all objectives are given equal weighted and non-dimensional this is the objective function which was use f0r optimization the parameters of the optimal designs are as shown in table

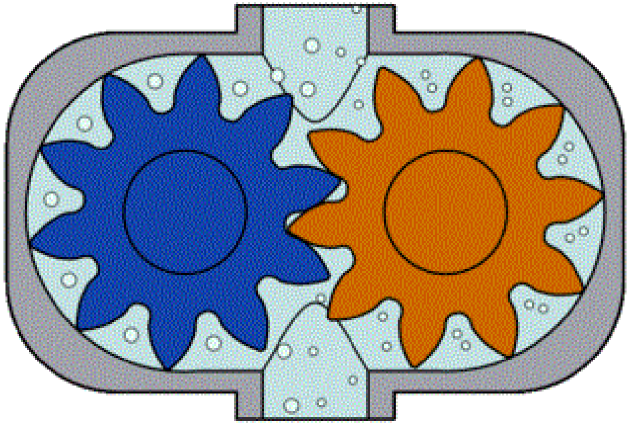


Fig 3.3: profile of optimize gear

Amongst design that had similar value for better objective, which are highest value for OF1 was picked.in dual flank operation flow range varies from 69 to 100%.

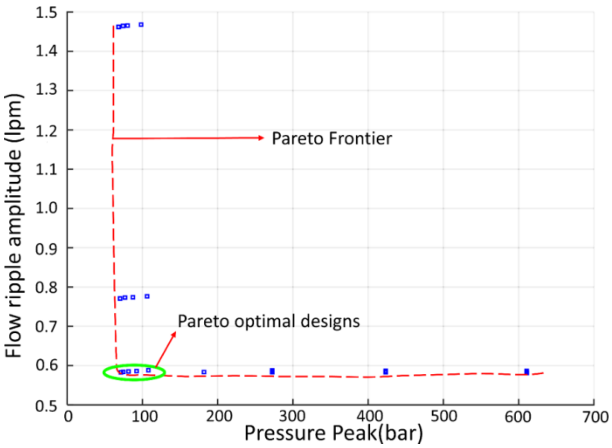


Fig 3.4: Pareto plot between OF2 and OF3

This flow variation corresponds a stroke length of 5.15 mm for the towards succession side for slider the optimal design which are selected also happens to belong the set of Pareto optimal design which plot between with few optimal design as shown in above fig (8)

IV. EXPERIMENTAL SETUP AND TEST RESULT

Experiment aim to measure the performance of design and verify its electronic flow reduction capability, for these the slider position was moved within the stroke length 0 to 5.15 mm towards succession port the equivalent ISO hydraulic circuit

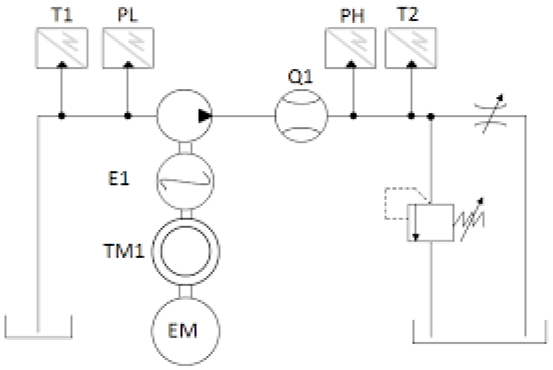


Fig 4.1. ISO schematic of test setup

By changing the setting the flow area orifice as its outlet pump delivery pressure as sown in fig 9 and whole delivery line is equipped with pressure measurement sensor, thermocouple and flow meter.

Test result:
The derived displacement of the pump can be obtained from the experimental result to make to get validation the displacement variation range calculated form experiment must match with numerical prediction of HYGESIM The displacement is derived is calculated using TOET method [15].

Fig 10 shown that flow rate versus delivery pressure for maximum displacement setting minimum.

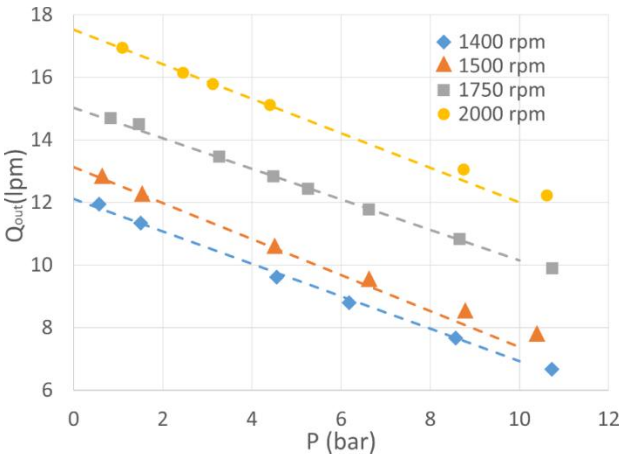


Fig 4.2: Flow Rate Versus Delivery pressure at maximum flow setting of the VD-EGP

Logically results at maximum setting follows the derived displacement at minimum setting which will be its lower predictable value which is observed by the experiment performed at minimum flow setting. That is
$\beta_{expt} = V_d,\min / V_d,\max$ (14)

hence,its derived that displacement measurement match the prediction of the numerical model. The relation between the flow rate and slider position is most important and the analytical formula of the curve will help to determine the flow control parameter and also the understanding what causes larger flow ripple at flow rate is reduced.

V. CONCLUSION

This reviewed paper presented a working concept for a “variable delivery flow external gear pump with electronics control of flow rate”.The design principal derived from variable timing concept of previously introduced by author’s team. The propose VD-EGP slider is design in such a way so that the slider always operate under the equilibrium of the pressure forces acting on it the lower cost and promoting the simplicity EGP design is asymmetric because of this reason design solution is suitable for medium and low pressure. This paper also analyze the kinematic flow rate for VD-EGP for different slider position. The traditional gearing manufacturing techniques used for mass production in manufacturing industry can easily overcome this difficulty as they can achieve ISO class accuracy because hence, this concept and design would be feasible for industrial application.

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