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Design of Hydraulic Pump to Increase the Flow Rate for Auxiliary Applications

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Abstract::*There are enormous ways to increase the lifting speed for auxiliary application, which includes increase the speed of the pump, separate flow for auxiliary application, this paper aim to design a new gear pump to increase the oil flow rate. Hydraulic power for the auxiliary applications reflects delivery of high-pressure oil to provide swift response during the operation. Hydraulic system functioning with a positive displacement piston pump is able to deliver a maximum oil flow of around 18 lpm. These 18 lpm oil flows are considerably low to offer a swift response, which results in productivity and revenue loss to the customer. To realize the desired requirement, it is essential to have a minimum flow of 25 lpm. The prevailing hydraulic systems have been studied and compared with various alternatives to understand the deficiency in the system. To optimize and evolve an optimum hydraulic system for auxiliary application various concepts options were evaluated these options has been funneled using Pugh methodology to firm up the design concept. A responsive hydraulic system has been created for the auxiliary application which offers adequate oil flow rate to have an effective performance.*

Keywords: *Hydraulic Pump, Auxiliary application, Flow rate, Pugh Matrix, Gear Pump*

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I. Introduction

Prevailing positive displacement hydraulic system has piston pump, cylinder, pump shaft, gear, external port and filter. It has a mechanism to create a reciprocating motion along an axis, and then builds pressure in a cylinder or working barrel to force fluid through the pump. Piston pump can run at a maximum speed of 701 rpm, whereby restricting the maximum delivery of oil flow to 21.14 lpm at no load condition. But an alternate way of using a gear pump with 11.5 cc and 12.5 cc running at a speed of 2394 rpm and 2250 rpm shall deliver oil flow of 27.53 lpm and 28.13 lpm respectively at no load condition. Given the delivery of low flow rate of oil in the prevailing system, response in lifting speed is not adequate when compared to gear pump option which offers a better option when the design is suitably customized. This could fulfill the voice of customer in the auxiliary applications, with the need to operate on a duty cycle of loading and unloading for around 10 times effectively as against the prevailing positive displacement pump which due to low response is restricted to less than 8 times in a day.

In general a positive displacement pump is expected to be efficient than the constant running gear pump, in the prevailing configuration it is getting restricted due to lower rotational speed as well with 80% efficiency of the pump results in poor response and performance of the hydraulic system when compared with an gear pump which is offering an efficiency of around 85%. To realize a higher lifting speed in an auxiliary application, minimum oil flow rate essential is more than 28.13 lpm in no load condition and more than 24 lpm in loaded condition. From table 1, increasing the speed and capacity of gear pumps increases the oil flow rate.
Scope of this report is to propose an alternate hydraulic system which is responsive to meet the functional requirements in an auxiliary application as desired by the customers,

- Study the prevailing arrangement to understand the function of hydraulic system, identify the problem and root cause to create alternate concept options.
- Analyze the pros and cons of the proposed concept and evaluate the concept based on the objective set against the selection criteria.
- Use the concept selection processes for evaluating various concept options, rate and rank concepts, combine and improve the shortlisted concept.
- Evolve criteria such as flow rate, lifting speed, Power loss, Noise level, Material and Tooling cost for the proposed concept.
- Recommend the shortlisted concept which meets the criteria which can meet the functional needs during auxiliary applications.

Table 1: Flow Rate Comparison

Option 1 (11.5 CC pump)		Option 2 (12.5 CC pump)		Prevailing option	
Pump Speed rpm	**Flow lpm**	**Pump Speed rpm**	**Flow lpm**	**Pump Speed rpm**	**Flow lpm**
No Load Condition					
1995	22.94	1500	18.75	467	14.09
2394	**27.53**	1800	22.5	561	16.9
		2250	**28.13**	701	**21.14**
Loaded Condition					
1995	19.5	1500	15.94	467	11.98
2394	**23.4**	1800	19.13	561	14.38
		2250	**23.91**	701	**17.97**

II. Literature Gap

Bahrkhalil (2011) derived the methodology to solve the flow rate of the piston pump and gear pump which aid to calculate it for the existing as well the new pump concepts under the different variables like speed, efficiency of the pump. Lift time is calculated using the basic methodology of flow vs. time calculation. Culpepper and Casey solved the drive power as well the power loss problem of the pump which aid to calculate the power loss for the existing as well the new pump concepts. Also they considered the efficiency of the gear pump is 85% which is also taken up as reference for the calculation. The literatures studied as part of this study is given a wider idea about the hydraulic pumps and its function which aid to find the solution for the defined problem. By analyzing the existing product problem and competitor performance new concepts are generated and then applied concept selection a process like combine and improve methodology is applied to get more concepts. After the concept generation process there is a need for identify suitable concept selection methodology to select the best concept. Pugh matrix methodology is applied to identify the best concept.

III. Methodology

Based on Stuart Pugh literature, the various parameters were studied for the defined problem and objective criteria's are identified. The criteria are analyzed based on the function, performance, customer requirement as well the business requirement. The selected objective criteria are as follows,

- Flow rate at 100% efficiency
- Flow rate at 85% efficiency
- Lift time at 100% efficiency
- Lift time at 85% efficiency
- Power loss
- Noise level
- Material cost

3.1. Flow Rate Calculation:

Flow rate of the positive displacement pump is calculated by product of pump volume and pump rotational speed and efficiency of the pump of 100% and 80% since 100% efficiency is considered as zero load condition or zero pressure condition and 80% efficiency is considered as maximum load or 185 bar pressure condition.

Volume of the prevailing hydraulic pump is 30.163 CC
Pump speed is 701 Erpm
Q = (Pump volume x Pump speed / 1000) x efficiency = (30.163 x 701)/1000) x 100%

Maximum Flow rate (Q) = 21.14 lpm

Q = Pump volume x Pump speed / 1000) x efficiency= (30.163 x 701/1000) x 80%

Minimum Flow rate (Q) = 16.92 lpm

3.2. Lifting Time Calculation:

Lifting time is the ratio of total volume of the cylinder and flow rate.

Lifting time = Total volume of the cylinder / Pump flow rate
Total volume of the cylinder is 0.01 m^3
Pump flow rate = 21.14 / (1000 x 60)
= $3.524E^{-04} m^3/sec$
Lifting time = 0.01 / $3.524E^{-04}$

Lifting time = 30.1 sec.

Pump flow rate = 16.92 / (1000 x 60)
= $2.819\ E^{-04} m^3/sec$
Lifting time = 0.01 / $2.819\ E^{-04}$

Lifting time = 37.6 sec.

3.3. Power Loss Calculation:

Drive power is the product of flow rate and pressure with respect to the efficiency of the pump.

Drive Power = Pump flow x Pressure / 600 * Efficiency
Pressure (p) = 185 bar
Drive Power at 100% = (21.14*185)/ (600*1)

P = 6.52 kW

Drive Power at 80% = (21.14*185*0.8)/ (600*1)

P = 8.15 kW

Power loss is the difference between 80% and 100% of the drive power.
Power loss = Drive power at 80% efficiency - Drive power at 100% efficiency
Power loss = 8.15 – 6.52

Power loss = 1.63 kW

3.4. Noise Level Measurement:

Prevailing positive displacement piston pump is mounted on the rig as per the installation condition. The pressure was increased from 0 to 180 bar, subsequently pump speed was changed from 312 rpm to 779 rpm and values of flow rates and noise levels are measured. The measured flow rate and noise values at different pump speed at 185 bar pressure condition are tabulated in Table 2. Generally noise increases due to excess vibration due to improper supports or mountings or increasing the speed of the pump. Noise level in the prevailing system is well accepted since there is no abnormal noise observed during the operation, so noise level in new pump should not exceed more than the 104 dB (A).

3.5. Concepts Generations:

The prevailing hydraulic systems have been studied and compared with various alternatives to understand the deficiency in the system and various concepts have been generated to increase the flow rate. All these concepts have been evaluated as per the objective requirement of high flow rate as per the functional requirement for an auxiliary application. Following concepts have been generated based on meeting the minimum oil flow rate requirements of 25 lpm at loaded condition,

- Positive displacement Piston pump with Higher speed (940 rpm).
- 14 CC Gear pump with 1:1 ratio.
- Hybrid Pump.
- Integrated pump.

A responsive hydraulic system has to be identified from above concepts to have an effective performance in auxiliary application. Positive displacement Piston pump with higher speed means increasing the pump speed from 701 rpm to 940 rpm to increase the flow rate. Hybrid pump is replacement of positive displacement piston pump with gear pump to develop the flow and pressure as desired and all other functional requirements are retained as is in prevailing system. Integrated pump is an additional gear pump which is included in the prevailing system to combine the piston pump and gear pump flow and delivers to the auxiliary application

Table 2: Noise Level Measurement

Pump speed	Pump Flow Rate (lpm)	Noise measurement dB(A)
312	7.81	96.5
467	11.69	98
540	13.52	98.6
623	15.60	100.2
701	17.55	101
779	19.5	103.6

3.6. Concept Selection Methodology:

Using Pugh matrix, it allows us to shortlist the appropriate concept against the given set of criterion such as flow rate, lifting speed, power loss, noise level, material cost whereby enabling us to evaluate the concept qualitatively whereby the sum of the positive rating determines the preferred option which qualifies to be pursued further for design detailing. When a concept exceeds, it fetches a positive rating value of +1, when it just about meets the requirements, it is neutral with a rating value of 0, when it does not meet the criteria it is rated as -1. Assigned ratings are summed up and total is calculated as in Table 3.

Table 3: Concept Selection Methodology

Criteria	Objective Values	Piston pump with higher speed		14 CC Gear pump 1:1 ratio		Hybrid Pump		Integrated pump	
Flow Rate at zero pressure	≥ 28.13 lpm	28.3	1	31.5	1	34.34	1	39.14	1
Flow Rate at max pressure	≥ 23.91 lpm	24.04	1	26.78	1	29.18	1	32.21	1
Lift Time at zero pressure	≤ 22.6 sec	22.51	1	20.2	1	17.47	1	16.3	1
Lift Time at max pressure	≤ 30.9 sec	26.48	1	27.6	1	20.56	1	19.8	1
Power Loss	≤ 1.63 kW	2.18	-1	1.72	1	1.58	1	2.61	-1
Noise Level	≤ 104 dB(A)	103.5	1	101	1	101	1	101	1
Material Cost	Rs. 5265 /-	9551	-1	14217	-1	5200	1	13902	-1
Score			3		5		7		3
Rank		4		2		**1**		3	

From Table 3, **HYBRID PUMP** has been shortlisted as preferred concept choice since it has qualified much higher than the other 3 choices and is expected to meet the functional requirement as desired for auxiliary application. Based on the theoretical calculation Hybrid pump will have a swift performance in auxiliary application since the flow rate at no load condition is 34.34 lpm and at loaded condition is 29.18 lpm which is significantly high as compare to the prevailing system.

IV. Results And Discussions

4.1. Working of Hybrid Pump:

Hybrid pump is external meshing gear pump which is directly mounted on the existing arrangement. The fig.1 indicates the construction of the hybrid pump and its parts as well flow of oil from filter to the external port. This hydraulic system comprises of hybrid gear pump, drive gears, external port, pipe kit, Filter. The pump is integrated with the filter which is being used to supply the filtered oil in to the pump. Gear 1 and gear 2 drives the pump shaft continuously at the speed of 701 rpm.

Due to the pump shaft rotation, gear 3 drives the gear 4 at the speed of 2250 rpm. The gear 4 is mounted on the gear pump shaft, which drives the internal gears of the pump to create the suction and delivery stroke. In this concept 14 CC gear pump with 1.019 ratios has been used to develop the required oil flow rate, lifting speed and optimum power requirement for auxiliary applications.

Control valve is mounted on the delivery port and it is direct the oil flow to the external port while operating the lever. The relief valve and check valve is placed on the delivery port and it is used for maintains the system pressure.

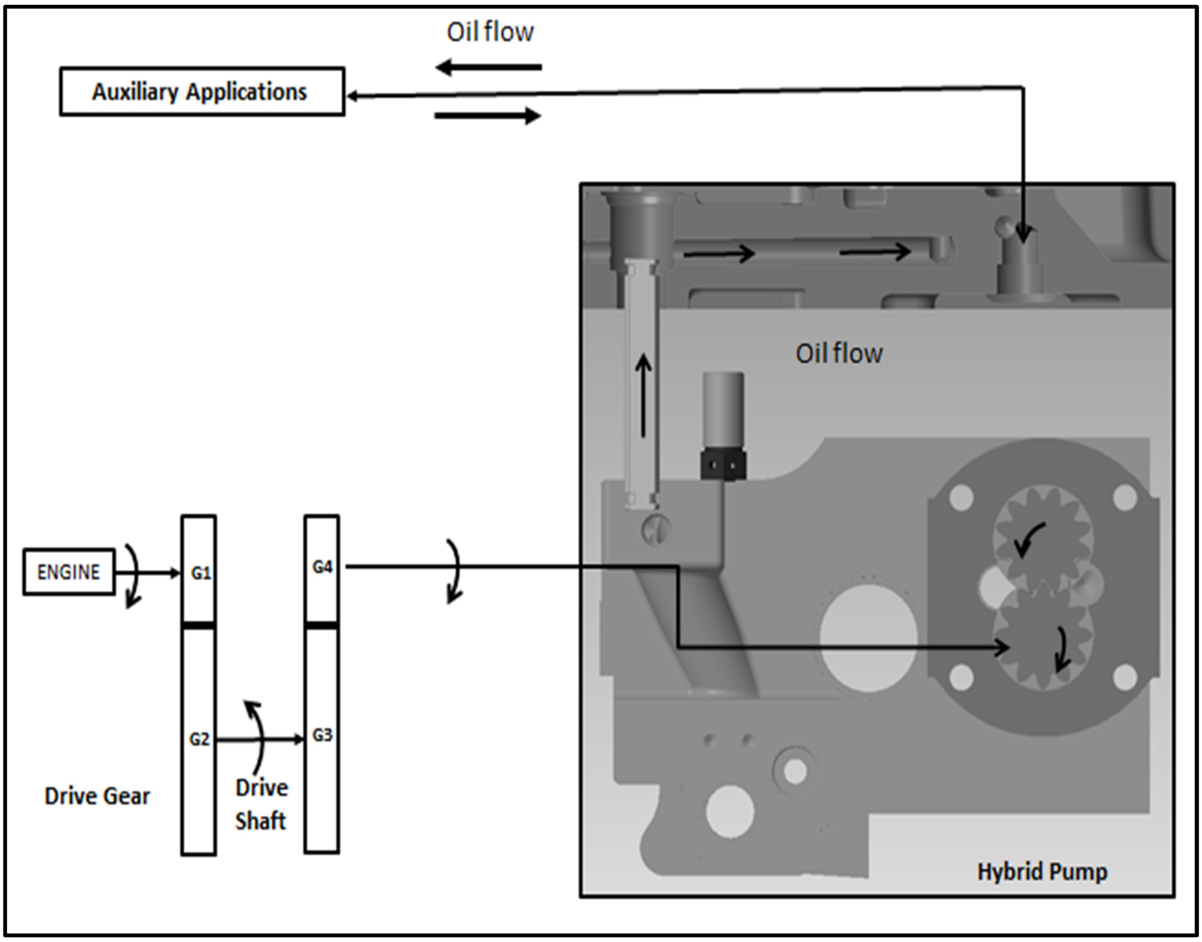

Fig.1 Schematic Diagram of Hybrid Pump

The external gear pump uses two identical gears rotating against each other, one gear is driven by a pump gear and it in turn it drives the other gear. Each gear is supported by a shaft with bush bearings on both sides of the gear.

As the gears come out of mesh, they create expanding volume on the inlet side of the pump. Oil flows into the cavity and is trapped by the gear teeth as they rotate. Oil travels around the interior of the casing in the pockets between the teeth and the casing, it does not pass between the gears. Finally, the meshing of the gears forces oil through the outlet port under the high pressure. This cycle will continuous throughout the working condition. Housing is made up of aluminium since it is having high rate of heat dissipation characteristic as well it prevents the gear failure if gears contact with the housing surface.

Housing has the suction and delivery passages as well it has sealing groves on the both sides to prevent the oil leakages. Bushes are also made up of aluminium which is used to support the driver gear and driven gears at both ends. The bushes having the oil groove which supply the oil to the shaft to avoid the wear and seizing. End cover is made up of steel bar and it is used to cover the entire assembly and supports the driver gear shaft. Oil seal is mounted on the end cover to avoid the oil leakages from the gear pump.

4.2. Hybrid Pump Test Results - Flow Measurement and Lift Time Comparison:

Oil flow has been measured using the flow meter with the different speed at zero pressure which reflects no load condition. After that system pressure has been increased up to 185 bar to create load on the pump, so as to measure the oil flow at different speeds. Post 185 bar pressure, the relief valve starts opening and oil discharges to the sump. The desired speed has been set by using the regulator since speed has been generated by the motor. The hybrid pump flows at loaded condition gives much higher flows than the theoretical considered efficiency rate of 85%.Flow at zero pressure and 185 bar pressure has been tabulated in Table 4. Lift Time comparison at Zero pressure and 185 bar pressure is tabulated in Table 5 and 6.

Lifting time = Total volume of the cylinder / Pump flow rate

Total volume of the cylinder is 0.01 m^3

Table 4: Flow Measurement

Pump RPM	Flow in lpm @ Zero pressure	Flow in lpm @ 185 bar pressure
1080	14.67	13.61
1261	17.13	15.54
1296	17.60	16.33
1526	20.72	19.01
1635	22.20	20.14
1728	23.47	22.01
1874	25.45	23.87
1962	26.64	24.72
2180	29.60	28.08
2430	33.00	31.30

Table 5: Lift Time Comparison at Zero pressure

PREVAILING SYSTEM			HYBRID PUMP			
Pump Delivery (lpm)	**Pump Delivery (m^3/sec)**	**Lifting time (sec)**	**Pump Delivery (lpm)**	**Pump Delivery (m^3/sec)**	**Lifting time (sec)**	**% of Time reduction**
9.41	1.568E-04	**67.6**	14.67	2.444E-04	**43.4**	**35.8 %**
14.09	2.348E-04	**45.2**	23.47	3.911E-04	**27.1**	**40 %**
16.29	2.715E-04	**39.1**	26.64	4.441E-04	**23.89**	**38.9%**
18.79	3.132E-04	**33.9**	32.27	5.378E-04	**19.73**	**41.8 %**
21.14	3.524E-04	**30.1**	33	5.500E-04	**19.29**	**35.9 %**

Table 6: Lift Time Comparison at 185 bar pressure

PREVAILING SYSTEM				HYBRID PUMP			
Erpm	**Pump Delivery (lpm)**	**Pump Delivery (m^3/sec)**	**Lifting time (sec)**	**Pump Delivery (lpm)**	**Pump Delivery (m^3/sec)**	**Lifting time (sec)**	**% of Time reduction**
1000	7.53	1.255E-04	**84.6**	13.61	2.268E-04	**46.78**	**44.7 %**
1500	11.27	1.878E-04	**56.5**	22.01	3.669E-04	**28.91**	**48.8 %**
1735	13.03	2.172E-04	**48.9**	24.72	4.120E-04	**25.75**	**47.3 %**
2000	15.03	2.506E-04	**42.3**	30.27	5.045E-04	**21.03**	**50.3 %**
2250	16.92	2.819E-04	**37.6**	31.30	5.216E-04	**20.34**	**45.9 %**

4.3. Hybrid Pump - Power loss Comparison:

Power loss has been calculated for new hybrid pump based on the flow rate measurement and compared with the prevailing system, the details are tabulated in Table 7. Power loss has been reduced more than 11% as compared to prevailing system.

Table 7: Power Loss Comparison

PREVAILING SYSTEM				HYBRID PUMP			
ERPM	**Power at zero pressure (kW)**	**Power at 185 bar (kW)**	**Power loss (kW)**	**Power at zero pressure (kW)**	**Power at 185 bar (kW)**	**Power loss (kW)**	**% of Power loss**
1000	2.90	3.62	**0.72**	4.40	5.00	**0.60**	**16.67 %**
1500	4.35	5.43	**1.09**	7.16	8.04	**0.88**	**19.27 %**
1735	5.03	6.28	**1.26**	8.17	9.18	**1.01**	**19.84 %**
2000	5.79	7.24	**1.45**	10.11	11.36	**1.25**	**13.79 %**
2250	6.52	8.15	**1.63**	10.56	12.00	**1.44**	**11.66 %**

4.4. Hybrid Pump Test Results - Noise Comparison:

Hybrid pump noise has been recorded by using decibel meter at different speeds and values are tabulated in Table 8. Noise values are well within limit since it is having addional mounting and bearing support than the prevailing system.

Table 8: Noise Comparison

Pump RPM	**Noise measurement dB(A) (Prevailing System)**	**Pump RPM**	**Noise measurement dB(A) (Hybrid pump 14 CC 1.09:1 ratio)**
312	96.5	1080	96.8
362	96.8	1261	97.5
374	97.4	1296	97.8
436	97.8	1526	98.4
467	98.0	1635	98.6
498	98.5	1728	100
540	98.6	1874	100.2
701	101.0	2430	101.8

V. Summary And Conclusion

Design of Hybrid pump with 1.09 ratio has been completed successfully, the results have been validated against the set objectives and it meets the given functional requirements. The details are tabulated in Table 9.

Table 9: Objective Analysis with Hybrid Pump

Objective	Target	Actual	Meets the objective
Oil flow	23.91 lpm	31.3 lpm	Yes
Lifting speed	0.044m/sec	0.058 m/sec	Yes
Dropping speed	0.025 m/sec	0.028 m/sec	Yes
Efficiency of the pump	85%	94%	Yes
Lifting time	30.9 sec	20.34 sec	Yes
Dropping time	39 sec	39 sec	Yes
Noise Level	104 dB(A)	101.8 dB(A)	Yes

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