PAPER • OPEN ACCESS

Energy conservation strategy in Hydraulic Power Packs using Variable Frequency Drive *IOP Conference Series: Materials Science and Engineering*

To cite this article: S Ramesh *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **310** 012041

View the article online for updates and enhancements.

Energy conservation strategy in Hydraulic Power Packs using Variable Frequency Drive

IOP Conference Series: Materials Science and Engineering

Ramesh.S[1*], S. Denis Ashok[2], Shanmukha Nagaraj[3], M. Lohith Kumar Reddy[1], Niranjan Kumar Naulakha[1], Adithyakumar. C.R[1].

[1] Department of Mechanical Engineering, SET, Jain University, Bengaluru, India.
[2] Department of Design and Automation, SMEC, VIT University, Vellore, India.
[3] Department of Mechanical Engineering, R V College of Engineering, Bengaluru, India.

*E-Mail: shankaranarayanaramesh@gmail.com

Abstract: At present, energy consumption is to such an extent that if the same trend goes on then in the future at some point of time, the energy sources will all be exploited. Energy conservation in a hydraulic power pack refers to the reduction in the energy consumed by the power pack. Many experiments have been conducted to reduce the energy consumption and one of those methods is by introducing a variable frequency drive. The main objective of the present work is to reduce the energy consumed by the hydraulic power pack using variable frequency drive. Variable Frequency drive is used to vary the speed of the motor by receiving electrical signals from the pressure switch which acts as the feedback system. Using this concept, the speed of the motor can be varied between the specified limits. In the present work, a basic hydraulic power pack and a variable frequency drive based hydraulic power pack were designed and compared both of them with the results obtained. The comparison was based on the power consumed, rise in temperature, noise levels, and flow of oil through pressure relief valve, total oil flow during loading cycle. By comparing both the circuits, it is found that for the proposed system, consumption of power reduces by 78.4% and is as powerful as the present system.

Keywords: *Energy conservation, Hydraulic power pack, Variable frequency drive, Power consumption, Flow of oil.*

1. Introduction

1.1. Energy conservation:

Energy is defined as the capacity of the system to do the required work. Energy conservation refers to the reduction in energy consumption by using less of an energy service [1, 2]. Energy conservation in a hydraulic system refers to the reduction in the amount of power consumed by the motor to produce the required pressure [3].

1.2. Variable Frequency Drive (VFD):

Variable frequency drive in hydraulic power pack is an important device used to vary the frequency between specified limits depending on the signal sent by the pressure switch [4]. Pressure switch is used to measure the pressure in the system and it sends a signal to the variable frequency drive, when the pressure reaches the specified limits. Depending on the signal, the frequency drive alters the speed of the pump. Variable frequency drive is connected in between the power source and the motor as shown in figure 1 and specifications of variable frequency drive were explained in Table 1.

Figure 1: Variable Frequency Drive

Table-1: Specifications of Variable Frequency Drive (VFD)

	Function	Specification
Input	Rated voltage; frequency	Three-phase: 380 to 460 V; 50/60 Hz
Output	Allowable change	Voltage: ± 10 %, frequency: 50/60 Hz ± 5 %
	Rated voltage	Corresponding input voltage
	Frequency range	0 to 300 Hz
	Overload ability	150 % rated current, 1 min; 200 % rated current, 0.5s

1.3. Hydraulic power pack system:

Hydraulic power pack is called as heart of any hydraulic system which supplies the pressurised fluid. It consists of a pump, motor, filter, pressure relief valve, variable frequency drive, reservoir etc. The motor drives the pump and the pump sucks the oil from the reservoir. The direction control valve controls the direction of fluid flow. Figure 2 explains the structure of hydraulic power pack which is used for the present work. The proposed hydraulic power pack consumes considerably lesser amount of power as compared with the available power pack during the process of operation at required pressure.

Figure 2: Hydraulic power pack

2. Working of the basic hydraulic power pack:

2.1. Cylinder is in motion:

Figure 3 explains the working of hydraulic power pack when cylinder is in motion. The hydraulic cylinder moves when the direction control valve is activated in either direction. Upon activation, oil flows from the direction control valve to the actuator, thereby inducing a pressure drop in the system. The motor continues to run at a constant rpm and this leads to a constant flow of hydraulic oil [5]. A major percentage of this hydraulic oil is used to move the actuator and a very small percentage of hydraulic flows through the pressure relief valve to the reservoir.
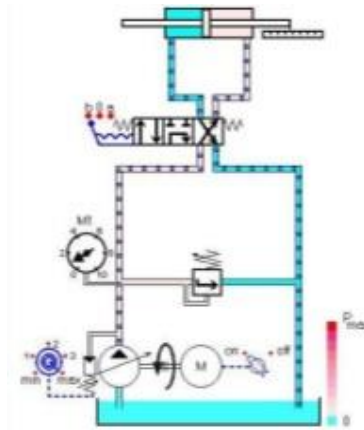
Figure 3: Cylinder in transition

2.2. Cylinder is at the Dead-end position:
The hydraulic cylinder will reach its dead-end positions once the direction control valve is activated. On reaching the dead-end position, the cylinder stays in that position till the direction control valve is activated again and flow occurs in the opposite direction. At the dead-end positions, the pump which is coupled to the motor runs at the same rpm as it was when the cylinder is in motion. The amount of oil that is pumped into the system remains the same. The motor runs at a constant speed of 1400 rpm regardless of the load on the system. Once the cylinder reaches either of the dead end positions, the pressure increases in the system to the maximum pre-set pressure (This is set in the Pressure Relief Valve). Upon reaching the pre- set pressure, in order to safeguard the equipment, present in the system, the pressure relief valve opens up and the oil flows back into the reservoir. As the motor runs at a constant rpm, the oil delivered by the pump remains constant. A certain percentage of this pumped oil maintains the required system pressure and the excess oil flows through the pressure relief valve into the reservoir. This unnecessary pumping of oil due to the constant rpm of the motor leads to unnecessary usage of power.

3. Working of the hydraulic power pack with VFD:
In conventional open loop hydraulic system, due to the absence of a feedback system, the motor runs at a constant speed regardless of the load which is due to the constant input AC supply [6]. With the introduction of a pressure switch and a Frequency Converter, Proposed System behaves as a closed loop system [7]. The pressure switch being the feedback element senses the pressure in the pressure ports and accordingly sends voltage signals to the frequency convertor. The frequency convertor in turn receives this signal and by design changes the input frequency to the motor ultimately varying its speed [8].

3.1. Present Conditions:
Pressure Relief Valve - 50 bar
Pressure Switch - 40 bar
3.1.1 Frequency Converter Settings
    Lower Frequency - 7 Hz
    Higher Frequency - 50 Hz
    Piston in transition (loaded condition /Extension / retraction):

When the actuator begins to extend, or retract, the pressure in the system drops to 20 bar. This drop-in pressure below 40 bar is sensed by the pressure switch which is mounted on the manifold block. This accordingly sends a voltage signal to the frequency convertor. The signals are as follows:

- 40 bar and above 24 volts
- Below 40 bar 0 volts

The frequency convertor receives this signal of 0 volts and automatically changes the input frequency of the motor to 50 Hz (1500 rpm). This increases the discharge from the pump so as to maintain the motion of the actuator [9]. When the actuator reaches the clamped position, the pressure in the pressure line increases to 50 bar as set by the pressure relief valve. But since the pressure switch is set to 40 bar, it detects this increase in pressure and sends a signal of 24 Volts to the frequency convertor. Once the frequency convertor receives this signal it reduces the input frequency of the motor to 7Hz (210 rpm) [10]. This decreases the discharge of oil from the pump and thus delivers just enough hydraulic oil so as to maintain the clamping pressure at 40 bar and the rest of the oil pumped which flows back to the tank through the pressure relief valve is reduced. Therefore, this reduces the unnecessary power consumption of the power pack and also reduces the heating of the oil considerably. It is because of the feedback mechanism that the efficiency of proposed system is much higher than any that of any other hydraulic power pack [11].

4. Calculations

4.1. At Frequency-1
Speed Calculations (N);
At a frequency f – 1 = 7 Hz
$N = (120 \times f - 1) / p$ rpm= 210 rpm   (Where p = number of poles in the motor)
Displacement of the pump (v) = 5.5 cc/rev = 5.5×10^{-3} litres / revolution.
Discharge by the pump (Q) = v x N lpm = 1.155 lpm
Power Consumed (Pw) = $(P \times Q) / (612 \times \eta)$ kW = 0.0889 kW
Where P = pressure (in bar), η = efficiency of the motor

4.2. At Frequency - 2
Speed Calculations (N)
At frequency f – 2 = 50 Hz
Speed; $N = (120 \times f - 2) / p$ rpm = 1500 rpm (Where p = number of poles in the motor)
Displacement of the pump (v) = 5.5 cc/rev = 5.5×10^{-3} litres / revolution.
Discharge by the pump (Q) = v x N lpm = 8.25 lpm
Power Consumed (Pw) = $(P \times Q) / (612 \times \eta)$ kW = 0.317 kW

4.3. Total power consumed:
(Using a 25 % loading cycle: 45 min clamped and 15 min loading)
In one hour, the total power consumed is as follows.
Total Power = [(Pw1 x 75 %) + (Pw2 x 25 %) x 60] kJ / hour = 0.1467 kW

4.4. Heat dissipation in a tank:
Conversion factors:
1 gpm = 0.06309 lps   1 psi = 0.06895 bar
$E L = 1.48 Q P (1 - \mu)$ Btu / hr = 280.76 Btu ⁄ hr
Where;
E L = Internal heat loss generated by pump and other components in Btu / hr
Q = Discharge of the pump in gpm
P = pump gauge pressure in psi
μ = System efficiency

5. Tests Conducted and comparing the systems:

5.1. Power Consumed by the present system and proposed system
Amount of power consumed can be calculated by each of the units under 25 % loading condition. The

present unit and proposed unit were subject to three trials of 30 minutes each and the power consumed by them with the actuator in use for 7 minutes and 30 seconds was noted down using a 3 phase 4 wire static Watt-hour meter as shown in Table 2.

Table 2: Power consumed by present and proposed system

Trial	Present System(kWh)	Proposed system(kWh)
I	1.25	0.3
II	1.25	0.26
III	1.25	0.24

Average power consumed by the present system = (1.25+1.25+ 1.25) /3 kWh = 1.25 kWh
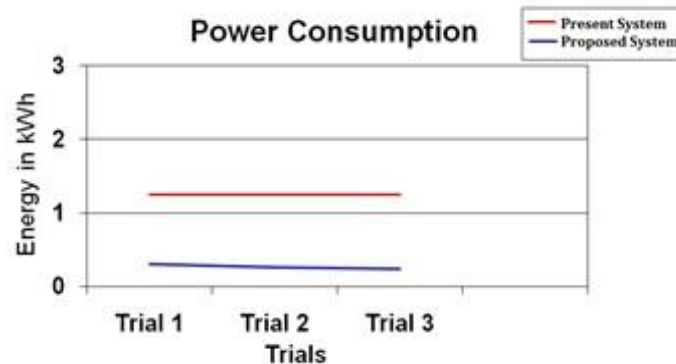Average power consumed by proposed system = (0.3 + 0.26 +0.24) / 3 kWh = 0.27 kWh

Figure 4

Figure 4 clearly explains the large amounts of power that is saved by using the power pack. With the following calculations, it was very clear that the proposed system saves up to 78% power.
Average power consumption by the present system = 1.25 kWh
Average power consumed by the proposed system = 0.27 kWh
Energy saved by using proposed system = 1.25 – 0.27 = 0.98 kWh [9]
Therefore, percentage of energy saved = (0.98 / 1.25) x 100 % = 78.4%

5.2. Temperature observed in the reservoir of the present system and proposed system
The temperatures of the oil in the two systems were observed using temperature indicators mounted on the reservoirs. The systems were run for thirty minutes continuously with a 25 % loading cycle, i.e. the actuators were utilized for 7 minutes and 30 seconds. Three trials were conducted and the reports are tabulated in table 3.

Table 3: Temperature of the oil in present and proposed system

Trial	Present System(ºC)	Proposed system(ºC)
I	15.00	5.90
II	13.00	4.28
III	14.00	4.20

Average rise in temperature in the present system = (15 + 13 + 14) / 3 ℃   = 14   ℃
Average rise in temperature in the proposed system = (5.90 + 4.28 + 4.20) / 3 ℃   = 4.80 ℃
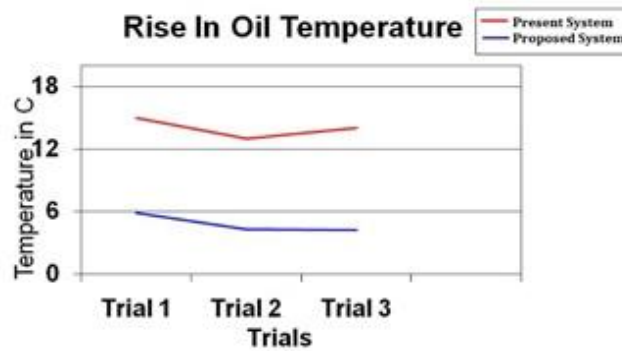
Figure 5

Figure 5 clearly shows the rise in temperature the oil undergoes when it is used in the present system. The rise in temperature in proposed system is just about 65% less than that of the present system.

Average rise in temperature in present system= 14 ℃
Average rise in temperature in proposed system = 4.80 ℃
Difference in oil temperature using proposed system= 14 − 4.80 = 9.2 ℃
Therefore, percentage decrease in temperature rise = (9.2 / 14) x 100 = 65.71%

5.3. The noise levels observed around the present system and proposed system

The noise levels around both the systems were measured using a sound analyser. The microphone of the analyser was mounted one metre away from the source. The systems were run for one minute with a 25 % loading cycle, i.e. 15 seconds with the actuator activated and 45 seconds without. Three such trials were conducted and the results are tabulated in table 4.

Table 4: Noise levels of present system and proposed system.

Trial	Present System(dB)	Proposed system(dB)
I	67.1	64.0
II	68.0	63.5
III	66.8	62.8

Table 5: Noise level comparison of both the system during loading and unloading conditions.

Action	Present system	Proposed system
Loading	69 dB	54 dB
Unloading	67 dB	71dB

The average dB value of present system is = (67.1 + 68.0 + 66.8) / 3 dB = 67.3 dB
The average dB value of proposed system is = (64.0 + 63.5 + 62.8) / 3 dB = 63.43 dB
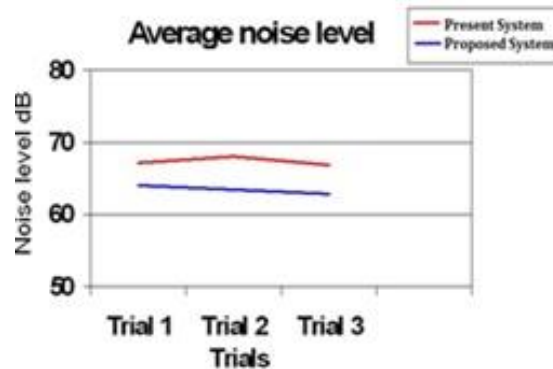

Figure 6

Figure 6 clearly shows the fact that proposed system is quieter in an industrial process.

5.4. The flow of oil through the PRV when the systems are clamped
The amount of oil that flows through the Pressure Relief Valve through both the systems were calculated with the help of a measuring tank attached to the hydraulic station. The time taken by the present system and proposed system to fill 1 litre of the measuring jar was recorded. Three such trials were conducted and the results were tabulated in table 6.

Table 6: Flow of oil through pressure relief valve for both present and proposed systems.

Trial	Present System(lpm)	Proposed system(lpm)
I	7.99	0.71
II	8.18	0.71
III	8.32	0.70

The average flow of oil through the present system through the PRV at the clamped position is = (7.99 + 8.18 + 8.32) / 3 lpm = 8.16 lpm
The average flow of oil through the proposed system through the PRV at the clamped position is = (0.71 + 0.71 +0.70) / 3 lpm = 0.71 lpm
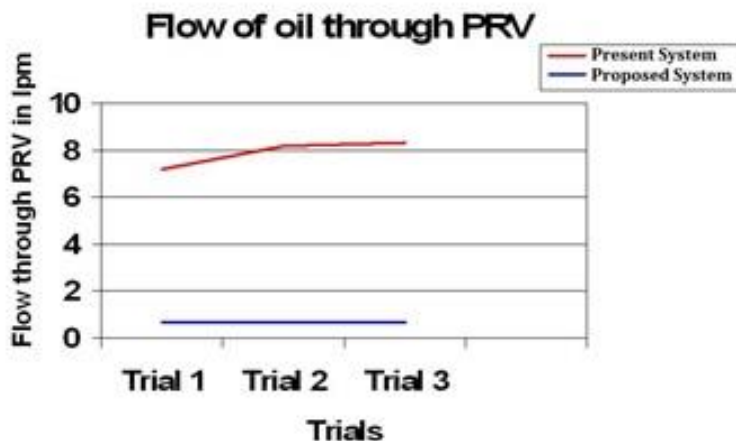

Figure 7

Figure 7 clearly explains the flow rate through the pressure relief valve in the present system is high in the clamped condition. The flow rate in proposed system is just about 8.7% of that in the present system.
Average flow rate in the present system = 8.16 lpm
Average flow rate in the proposed system= 0.71 lpm
Difference in the flow rate= 8.16 – 0.71 = 7.45 lpm
Therefore, percentage of flow reduced = (7.45 / 8.16) x 100 % = 91.30 %
This reduction in flow shows that the proposed system works at a higher efficiency and the heating of the oil is also reduced considerably.

5.5. Total flow oil through the system during loading cycle
The amount of oil that flows through the systems during the loading cycle was calculated with the help of a measuring tank attached to the hydraulic station. The time taken by the present system and proposed system to fill 1 litre of the measuring jar was recorded. Three such trials were conducted and the results were tabulated in table 7.

Table 7: Flow of oil through the system during loading cycle.

Trial	Present System(lpm)	Proposed system(lpm)
I	9.42	9.05
II	9.26	8.91
III	9.35	9.34

The average flow of oil through the present system = (9.42 + 9.26 + 9.35) / 3 = 9.34 lpm
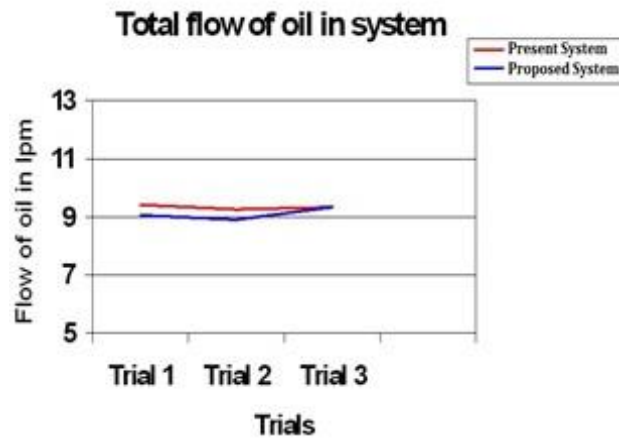The average flow of oil through the proposed system = (9.05 + 8.91 + 9.34) / 3 = 9.1 lpm

Figure 8

Figure 8, clearly shows the fact that the flow rates in both the systems is nearly the same. This proves the fact that proposed system is as powerful as the present system in the loading condition and can perform the same tasks.

6. Comparison of cost of running the machines
When the machines are run for 24 hours a day; Cost (INR) = P x 24 x 300 x 5.16

Where P = average power consumption in 1 hour (kWh)
When the system works for 24 hours a day for 300 days a year at Rs. 5.16 / kWh (Source KPTCL)
Running of present system for 24 hours. Cost = 2.5 x 24 x 300 x 5.16 (Rs) = Rs 92,880 /-
Running of proposed system for 24 hours. Cost = 0.54 x 24 x 300 x 5.16 (Rs) = Rs 20,062 /-

6.1. Amount saved annually
Rs 92,880 - Rs 20,062 = Rs 72,818 /-
i.e. (72,818/92,880) x 100 = 78.40 %

Figure 9

When the system runs the whole day, the above calculations shows that it saves around 78% of the money spent.

Table 8: Comparison of various parameters used for both present and proposed system

Parameter	Present System	Proposed system
Reservoir	40 L	30 L
Motor	2.2 kW	0.75 kW
Motor mounting	Horizontal; Space consuming	Vertical; Compact
Pump	Double Vane pump	1 Gear pump
Pump placement	Mounted on the top plate	Fully immersed in the reservoir
System	Open loop system	Closed loop system
Speed of motor	Constant 1440 rpm	Range of 200 -1500 rpm
Feedback	No	Yes; Pressure switch
Frequency Converter	No	Yes
Power Consumed	1.25 kWh	0.27 kWh
Rise in temperature of oil	14 °C	4.80 °C
Cost to run for 24 hrs a day for 300days	Rs 92,880 /-	Rs 20,062 /-
Flow through PRV	8.16 lpm	0.71 lpm
Maximum oil flow	9.34 lpm	9.10 lpm
Noise level	67.3 dB	63.43 dB
Aesthetics	Bulky and over utilization of floor space	Compact and occupies less space

From table 8, it is very clear that proposed system is a very efficient system as compared to the present system.

7. Conclusion:

The proposed system is advantageous compared to the present system. Because of the lack of the feedback system in the present system, motor runs at the same speed regardless of the pressure in the circuit and consumes more amount of power. But the proposed system has a feedback system which uses pressure switch and sends a signal to the variable frequency drive when the specified pressure is reached thereby reducing the power consumed. The power saved by using the proposed system is about 78%, temperature rise is decreased by about 65%, flow is reduced by about 91%, noise level reduced by 5.75% and the power difference in the systems is 2.57% i.e., the proposed system is quieter and is as powerful as the present system. When the proposed system runs for the whole day, it saves around 78% of the money annually compared to the present system.

8. References:

[1] Ramesh S et.al, 2017, "*An Energy Conservation Strategy using variable frequency drive for a Hydraulic clamping system in a CNC Machine*", Elsevier Materials Today: Proceedings ICMMM.

[2] Ramesh S et. al., "*A review paper on optimization of energy efficient systems in machine tool technology*", STM Journal, trends in machine design Volume-2, Issue-2, pp 1-8.

[3] Annapurna Biradar and Ravindra G. Patil, April 2013, "*Energy Conservation Using Variable Frequency Drive*", IJETEE, volume-2, Issue-1.

[4] Tamal Aditya et.al, June 2013, "*Research to study Variable Frequency Drive and its Energy Savings*", IJSR, India Online ISSN: 2319-7064, Volume 2, Issue 6.

[5] Sumedh Tonapi et.al, 2015, "*Speed Control of AC Motor Using VFD*", International Journal of Innovative and Emerging Research in Engineering, Volume 2, Issue 3.

[6] Hebri S et.al.2012 "*Variable Frequency Drive Importance in an LPG Plant: Case Study*". J Elec Electron 1:101. doi:10.4172/2167-101X.1000101, Volume 1, Issue 1.

[7] Nasir Khalid et.al., 25 August 2014, "*Efficient Energy Management: Is Variable Frequency Drives the Solution*", Social and Behavioral Sciences, Volume 145, Pages 371-376.

[8] Mohandas R et al., March 2013, "*Energy Saving Mechanism Using Variable Frequency Drives*", International Journal of Emerging Technology and Advanced Engineering, Volume 3, Issue 3, Pages2250-2459.

[9] A. de Almeida, F. Ferreira, and D. Both, "*Technical and economical considerations in the application of variable-speed drives with electric motor systems*", IEEE Trans. Ind. Appl., vol. 41, no. 1, pp. 18.

[10] Pinkle J. Bhatt et.al, December 2014, "*Energy conservation in automatic fluid flow control using variable frequency drive*", International Journal of Advanced Technology in Engineering and Science, Volume No.02, Issue No. 12, ISSN (online): 2348 – 7550.

[11] James Will Gray and Frank J. Haydock, May/June 1996, "*Industrial power quality considerations installing Adjustable Speed Drive Systems*", IEEE Transactions on Industry Applications, Vol. 32, no. 3, pp. 646-652.

[12] P. Y. Keskar et.al, March/April 1996, "*Specification of variable frequency drive systems to meet the New IEEE 519 Standard*", IEEE Transactions on Industry Applications, Vol. 32, no. 2, pp. 393-402.

[13] Lawrence Ambs and Michael M. Frerker, March 2010, "*The Use of Variable Speed Drives to Retrofit Hydraulic Injection Molding Machines*", a report submitted to department of mechanical university of Massachusetts Amherst.

[14] M. K. Langfeldt, Feb 4 1980, "*Economic considerations of variable speed drives*", presented at ASME Energy Technology Conference and Exhibition.

[15] Rajendrakumar Patel. et al., February 2015, "*Energy Conservation Opportunity with a Variable Frequency Drive in Boiler Feed Pump*", International Journal of Application or Innovation in Engineering & Management (IJAIEM), Volume 4, Issue 2, pages 181-188.