Modification Of BFW SPM Machine By Developing A Strategy To Reduce Its Power Consumption.

Akash Kisan Mane
Department of Mechanical Engineering,
Nutan Maharashtra Institute Of Engineering And Technology
Pune, India

Nayan Vitthal Kadam
Department of Mechanical Engineering,
Nutan Maharashtra Institute Of Engineering And Technology Pune, India

Aditya Sudhakar Patil
Department of Mechanical Engineering,
Nutan Maharashtra Institute Of Engineering And Technology Pune, India

Ajim Rasul Shaikh
Department of Mechanical Engineering,
Nutan Maharashtra Institute Of Engineering And Technology Pune, India

Anuj Khond
Department OF Mechanical Engineering,
Nutan Maharashtra Institute of Engineering And Technology Pune, India

Abstract— In modern manufacturing, the optimization of energy usage and operational efficiency is paramount to ensure competitiveness and sustainability. This research focuses on enhancing the efficiency of the BFW Special Purpose Machine (SPM) by addressing the excessive power consumption inherent in its hydraulic clamping system. The machine relies on an electric motor-driven hydraulic clamping system to secure workpieces on the machine table. However, the current configuration poses a significant challenge: the motor operates at a constant speed throughout the machining process, regardless of the fluctuating flow requirements of the hydraulic system. To rectify this inefficiency, we have implemented a novel solution. By integrating a Variable Frequency Drive (VFD) and an analog pressure sensor into the motor drive of the hydraulic clamping system, we can dynamically adjust the motor speed in response to varying load conditions. This adaptive approach optimizes power consumption, minimizing energy wastage without compromising operational effectiveness. Through systematic analysis and testing, the efficacy of this strategy in reducing power consumption will be rigorously evaluated. The outcomes of this research hold promise not only for enhancing the performance of the BFW SPM machine but also for advancing sustainable manufacturing practices on a broader scale.

Keywords— SPM machines; Hydraulic Circuit; Energy efficiency; SPM machines; Variable frequency drives

I. INTRODUCTION

In today's rapidly evolving industrial landscape, the imperative to conserve energy has become increasingly pronounced, particularly within the manufacturing sector [1]. With sustainability at the forefront of global initiatives, optimizing energy usage has emerged as a critical endeavor for businesses seeking to reduce costs, enhance competitiveness, and minimize environmental impact [2]. This imperative underscores the significance of research endeavors aimed at mitigating energy inefficiencies within manufacturing processes[3].

A. *BFW Special Purpose Machine*

One such area of focus lies within the domain of Special Purpose Machines (SPMs), which play an integral role in facilitating precision manufacturing across diverse industries[4]. Among these, the BFW SPM machine stands out for its versatility and capability in executing a wide array of machining tasks with unparalleled accuracy and efficiency [5]. Central to the functionality of the BFW SPM machine is its hydraulic clamping system, a vital component responsible for securing workpieces onto the machine table during machining operations. [6]

Fig1. Photograph of BFW SPM machine considered in the present study.

B. *Hydraulic Clamping System*

The hydraulic clamping system embodies both the ingenuity and complexity inherent in modern manufacturing equipment [7]. By harnessing the power of hydraulic pressure, this system provides robust and reliable clamping force, ensuring the stability and accuracy of machining processes [8]. However, despite its efficacy, the hydraulic clamping system of the BFW SPM machine encounters a notable challenge: excessive power consumption [9].

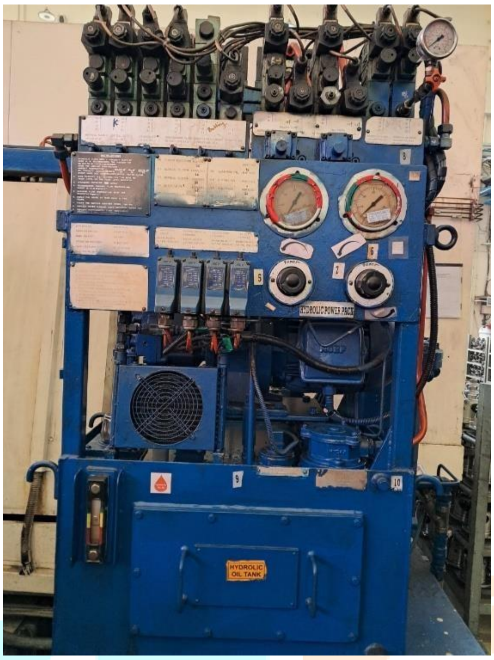


Fig2. Photograph of Hydraulic Clamping system employed in BFW SPM machine considered in the present study.

At the heart of this challenge lies the conventional operation of the hydraulic clamping system's electric motor, which runs at a constant speed throughout the machining process [10]. This static approach to motor operation fails to account for the dynamic nature of flow requirements within the hydraulic system, leading to energy wastage and inefficiencies [11]. Consequently, there arises a compelling need to devise innovative strategies to mitigate this issue and optimize energy utilization within the hydraulic clamping system of the BFW SPM machine [12].

This research endeavors to address this challenge by proposing a novel approach to energy conservation within the manufacturing sector ` By integrating advanced technologies such as Variable Frequency Drives (VFDs) and analog pressure sensors into the hydraulic clamping system, we aim to develop a dynamic control mechanism capable of adjusting motor speed in real-time based on fluctuating load conditions [15]. Through systematic analysis and experimentation, we seek to demonstrate the efficacy of this approach in reducing power consumption while maintaining operational effectiveness.

In essence, this research not only underscores the critical importance of energy conservation in manufacturing but also highlights the potential of innovative solutions to drive sustainable advancements within the industry. By optimizing energy utilization within the hydraulic clamping system of the BFW SPM machine, we strive to pave the way for enhanced efficiency, cost-effectiveness, and environmental stewardship in manufacturing operations.

II. DESCRIPTION OF EXSITING HYDRAULIC CLAMPING SYSTEM EMPLOYED IS THIS BFW SPM MACHINE

In this study the experimental work has been carried for the reduction of electrical energy consumption of a hydraulic clamping system in a SPM machine , manufactured by Bharat Fritz Werner Ltd., is engineered to provide reliable clamping force for machining operations. With a specified pressure requirement of 63 bar for clamping operations, this system is designed to ensure secure positioning of workpieces on the machine table during machining processes. At its core, the system features a robust 3.7 kW power pack electric motor drive, which serves as the prime mover for driving the hydraulic components.

A. Specifications of existing hydraulic clamping system

Sr.No	Description	Values
1	Make	Bharat Fritz Werner Ltd.
2	Motor capacity	3.7kW
3	Rated motor speed	1500 rpm
4	Pump type	Geared pump
5	Pump displacement	16cc/rev
6	Maximum pressure	65 bar
7	Maximum flow	30 lpm
8	Clamping pressure	63 bar
9	Oil used	Hydraulic oil of grade 68

Table 1. Specification of the existing hydraulic pumping system

III. OPERATION OF EXISTING HYDRAULIC CLAMPING SYSTEM

The existing hydraulic circuit in the BFW SPM machine operates on an open-loop system, where the hydraulic pump supplies pressurized fluid to the hydraulic cylinder without continuous feedback or control mechanisms. Upon activation, the electric motor drives the hydraulic pump, which pressurizes hydraulic fluid drawn from the reservoir. The pressurized fluid is then directed to the hydraulic cylinder, exerting force on the clamping mechanism to securely hold the workpiece during machining. Throughout operation, the hydraulic pump maintains a constant rate of fluid delivery, sustaining the clamping force without adjustments based on system performance. While this setup provides basic functionality for clamping operations, its lack of feedback mechanisms limits adaptability and efficiency, presenting opportunities for optimization to enhance performance and energy efficiency.

IV. ENERGY CONVERSATION STRATEGY USING VFD IN HYDRAULIC CIRCUIT

The modified hydraulic clamping system which involves the integration of VFD variable frequency drive and analog pressure sensor to control the speed of the motor according to the flow variation using closed loop feedback system is shown in the figure,

Fig3. Modified Hydraulic Clamping System in BFW SPM.

The energy conservation strategy implemented in the hydraulic circuit of the BFW SPM machine integrates a Variable Frequency Drive (VFD) and an analog pressure sensor to optimize power consumption and operational efficiency. The VFD governs the speed of the electric motor, which drives the hydraulic pump, by adjusting the frequency and voltage of the AC supply based on analog signals received from the pressure sensor. This sensor continually monitors hydraulic pressure within the system, providing real-time feedback on variations in pressure levels. In response to these fluctuations, the VFD modulates motor speed to maintain optimal flow rates and clamping force while minimizing energy expenditure. Through this closed-loop feedback mechanism, the hydraulic circuit operates with heightened adaptability and responsiveness, optimizing energy utilization and enhancing overall system performance. This innovative approach underscores a commitment to sustainable manufacturing practices, driving efficiency gains and cost reductions in industrial operations.

As the speed of the motor is controlled by the supply voltage using VFD, the general hydraulic characteristics of the pump, including pressure, flow rate, power, and speed, vary in accordance with changes in motor speed. This phenomenon can be elucidated by the affinity laws in hydraulics, which describe the relationship between pump performance parameters and motor speed variations.

The affinity laws are represented by the following equations:

i) Law-I: ***Flow is proportional to the Shaft Speed i.e.***

$$Q_1/Q_2 = N_1/N_2$$

ii) Law-II: ***Pressure is Proportional to the Square of Shaft Speed i.e.***

$$H_1/H_2 = (N_1/N_2)^2$$

iii) Law-III: ***Power is Proportional to the Cube of Shaft Speed i.e.***

$$P_1/P_2 = (N_1/N_2)^3$$

Where ,
Q is volumetric flow rate in LPM
N in Shaft Rotational Speed in rpm
H is Pressure in Bar
P is power in kW

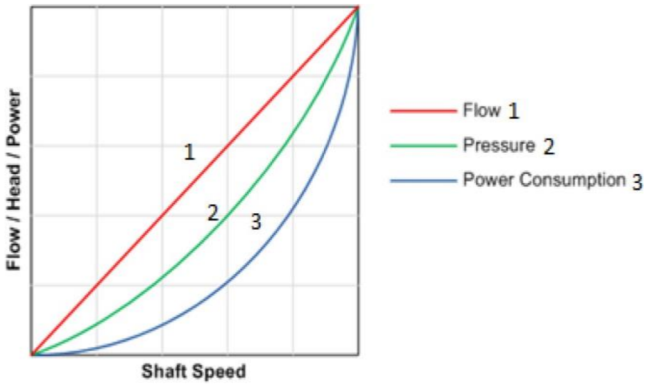


Fig4. Modified Hydraulic Clamping System in BFW SPM.

These equations of affinity laws demonstrate how changes in motor speed affect the hydraulic performance of the pump, illustrating the interdependence between motor speed, flow rate, pressure, and power in hydraulic systems controlled by a VFD. The experimental results are analyzed using affinity laws and are discussed below in section 5.

A. C.losed loop feedback system using digital analog pressure sensor.

In the closed-loop feedback system employing a digital analog pressure sensor, hydraulic pressure within the circuit is continuously monitored and precisely regulated for optimal performance and efficiency. Upon initialization, the sensor begins detecting variations in pressure, converting analog signals into digital data for transmission to the control system. Utilizing this data, the control system processes information, making real-time adjustments to system parameters such as motor speed or valve settings to maintain hydraulic pressure within desired limits. This dynamic feedback loop ensures stable and efficient operation under changing conditions, allowing for adaptive control and optimization of the hydraulic circuit. By continuously monitoring and adjusting system parameters, the digital analog pressure sensor facilitates enhanced performance and energy efficiency, contributing to the overall effectiveness of the hydraulic system.

V. CALCULATIONS

The electric power consumption for the given pressure and discharge can be calculated by using following equation,

Power consumed P’ = (P x Q) / (612 x ɳ) kW …… (1)
Where, P’- Power
P - Pressure in bar
Q - Discharge in lpm

η - Efficiency (85%)

The discharge of hydraulic fluid depends on the speed of rotation of the electric motor and it is calculated using the following equations (2) & (3) .

Discharge Q = v x N lpm ….(2)

Speed of a motor N = (120 x f) / p rpm …..(3)

Where p - no. of poles in the motor,
f – Frequency in Hz

1. Without VFD

Assuming machining time for 1 hour.
For, P = 63 bar
Q =22 lpm
η = 0.85
Power consumed= (P_w) = (P x Q) / (612 x η) = 2.7 KW

2. With VFD

For minimum speed,

Frequency f = 20 Hz when P = 43
Number of poles p = 4
Displacement of the pump v = 13.5 cc/rev = 13.5 x 10^-3 liters/ revs
Efficiency of the pump η = 85% = 0.85
Speed (N) = (120 x f) / p = 600rpm
Discharge by the Pump (Q) = v x N =8.1 lpm
Power consumed by the pump (PW1) = (P x Q) / (612 x η) = 0.7 KW

For maximum speed,

Frequency (f) = 50 Hz when , P =55 bar
Number of poles p = 4
Displacement of the pump v = 13.5 cc/rev = 13.5 x 10^-3 liters/ revs
Efficiency of the pump η = 85% = 0.85
Speed (N) = (120 x f) / p = 1500rpm
Discharge by the Pump (Q) = v x N =20.5 lpm
Power consumed by the pump (PW2) = (P x Q) / (612 x η)= 2.141 KW

VI. RESULTS AND DISCUSSIONS

The proposed energy conservation strategy were developed to enhance the efficiency of BFW SPM machine by reducing the power consumption through integration of a Variable Frequency Drive (VFD) and an analog pressure sensor in the hydraulic clamping system.

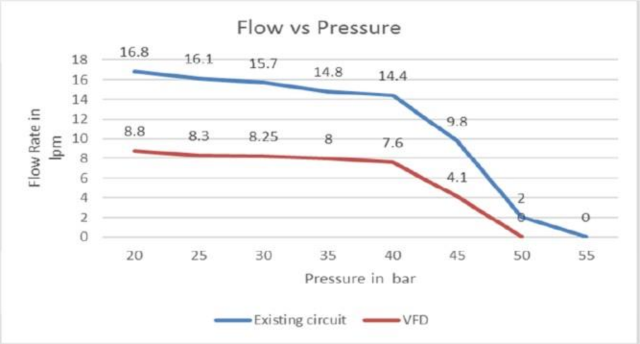
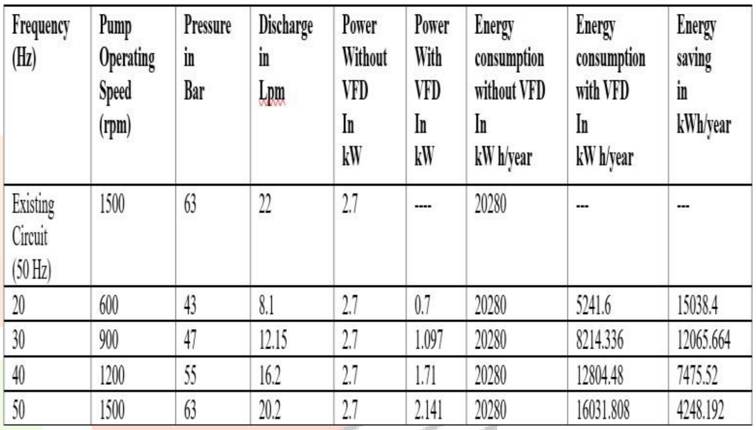


Fig.5 Pressure-Flow characteristic curve for the pump used for clamping operation

The following table shows the effect of speed variations of the VFd based hydraulic system and energy conservation of the modified hydraulic clamping system.

Table:2 Effect of speed variations of proposed VFD based hydraulic system and Energy conservation of proposed hydraulic system.



Frequency (Hz)	Pump Operating Speed (rpm)	Pressure in Bar	Discharge in Lpm	Power Without VFD In kW	Power With VFD In kW	Energy consumption without VFD In kW h/year	Energy consumption with VFD In kW h/year	Energy saving in kWh/year
Existing Circuit (50 Hz)	1500	63	22	2.7	----	20280	---	---
20	600	43	8.1	2.7	0.7	20280	5241.6	15038.4
30	900	47	12.15	2.7	1.097	20280	8214.336	12065.664
40	1200	55	16.2	2.7	1.71	20280	12804.48	7475.52
50	1500	63	20.2	2.7	2.141	20280	16031.808	4248.192

Thus from the experimental observations it is noticed that the existing hydraulic clamping circuit operates at constant speed of 1500 rpm throughout the entire machining operation for the supply frequency of 50 Hz which consumes the energy 65kWh per day i.e, 20280 kWh per year. However the modified hydraulic circuit the energy consumption varies from 5241.6 kWh to 16031.8 kWh per year.
Thus on further observation and calculations it is observed that the total energy saving by modified BFW SPM machine after the integration of vfd and analog pressure sensor in hydraulic clamping circuit is 65 kwh/day to 51 kWh per/day. That means 14 kWh energy/day is saved by the machine. Assuming 312 working days per year and 9 Rs per kWh electricity charges (14 kWh * 312 days * 9 Rs) = Rs 39312/- cost is saved by saving 4368 kWh energy/year.

A. Analysis of effect of speed variations on pump characteristics using VFD

The modified VFD-based hydraulic system varies the motor's speed by adjusting the motor's supply voltage frequency in response to changes in the load during clamping operation. Using the affinity laws, the impact of speed variations on the pump characteristics is examined; the findings are shown in Table 2. It is evident that an increase in supply frequency of 5 Hz corresponds to an increase in the electric motor's speed of 150 rpm. As the electric motor speed increases, the pump's flow rate also increases; as a result, the pump's flow rate tends to grow as the electric motor speed increases, as seen in Fig7(a). The pressure head, which is graphically depicted in Fig. 7(b), increases linearly with regard to the increase in motor speed as the flow rate in the hydraulic circuit increases.

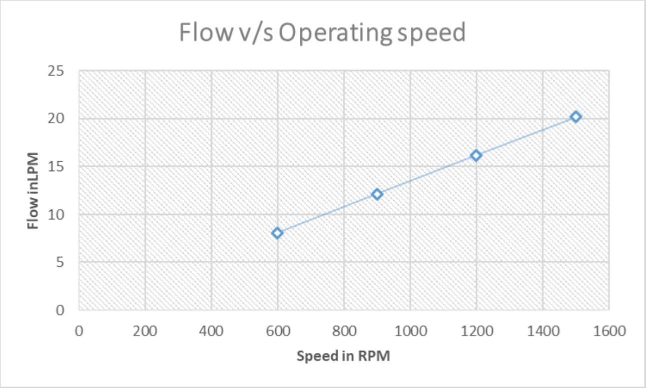


Fig. 7. (a) Flow rate

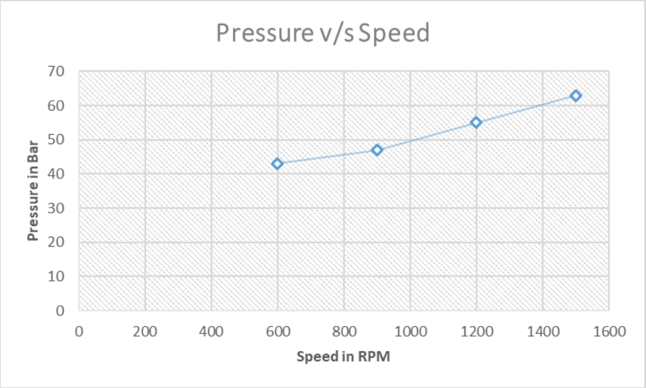


Fig. 7. (b) Pressure

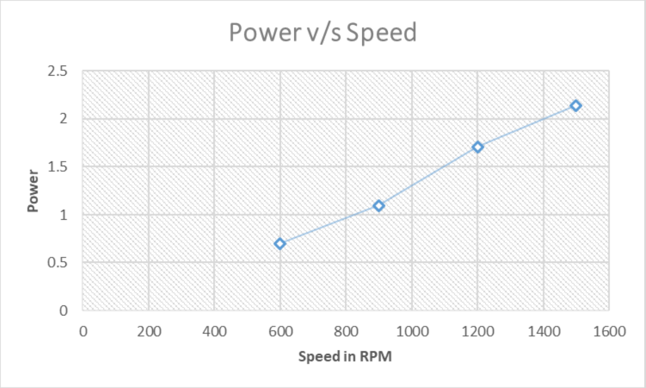


Fig. 7. (c) Power consumption

Fig.7. Effect of speed variations on the characteristics of the proposed hydraulic system.

In the hydraulic circuit, an increase in flow rate and pressure head results in a corresponding rise in motor speed, which also raises the motor's power consumption. As a result, as the motor speed increases, so does the power consumption, as seen graphically in Fig. 7(c). These findings support the suggested hydraulic circuit's speed-dependent behavior.

VII. CONCLUSIONS

In conclusion, the research endeavor focused on enhancing the efficiency and sustainability of the BFW SPM machine through the development and implementation of a novel strategy aimed at reducing power consumption in the hydraulic clamping system. By integrating a Variable Frequency Drive (VFD) and an analog pressure sensor, the study successfully demonstrated significant improvements in energy efficiency, operational performance, and cost- effectiveness. The results of comparison of pressure flow characteristics of the existing hydraulic clamping system and the modified system is presented. And from the experimental results it is observed that the modified hydraulic system of BFW SPM machine works at lower flow rate achieving the pressure of 63 bar required for clamping operation due to speed variation capability than existing hydraulic system. The existing Hydraulic clamping system circuit uses constant speed motor operating at 1500 rpm for the supply frequency of 50 Hz which consumes energy 20280 kWh/year. After implementation of VFD and analog pressure sensor in the existing hydraulic clamping system oif BFW SPM machine controlled the speed of motor for different frequency which results in significant energy saving. Additionally, the improved performance and stability of the hydraulic clamping system enhance the overall productivity and competitiveness of the manufacturing process.

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