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Energy Conservation Approach and Control Strategy for Open Loop, Closed Loop Hydraulic Circuit in CNC Machines

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Abstract – *An energy crisis is one of the major aspects that the world is facing today. There is a mismatch between the energy supply and demand which keeps on increasing every year. It is necessary to reduce the consumption of energy without disturbing the performance of the system. A number of researches have been carried out on various experiments in this field in order to find out energy-efficient electro-hydraulic circuits used in CNC machine tools. In the present paper, a detailed literature survey was carried out on the recent works in the field of an electro-hydraulic system to find out the methods that researchers have adopted to reduce the energy consumption and increase the system efficiency. Attempts were made to understand and incorporate the concepts of fuzzy logic, VFD in the hydraulic circuit to achieve the goal. A detailed literature survey was carried out on drive technology in hydraulic circuits for energy efficiency, control strategies of open loop hydraulic system with a closed loop intelligent control system and design modification in electro-hydraulic circuits for leakage losses.*

***Keywords**: Energy Efficiency, Variable Frequency Drives (VFD's), Electro-Hydraulic Systems, CNC Machines, Control Strategies*

I. Introduction

Energy efficient machine tools have become the need of the hour in the present-day industries, as the importance of energy efficiency is more pronounced by industrial economists. They generally consist of various motors and auxiliary components whose energy usage can vary strongly during machining. A detailed study of manufacturing processes and the power consumption of individual components, the possibility for energy savings can be calculated and trials can be distinct for the efficient use of energy. Production efficiency is essential for the machines and their products. Further researches have revealed that a large amount of unfavorable effect in the environment by machine tools is the energy consumption throughout the operation. Cost of the energy also contributes to a double-digit percentage of entire progress. Machine tools energy efficiency is a common topic with inspiration coming from a number of sides: machine builders and operators directing at reducing the processing costs, the regulation required to reduce ecological impact, as well as social aspects well thought out by clients and shareholders [1]. Energy consumption and energy efficiency are gaining awareness in the consumer market as a significant feature in industrial equipment. A recent investigation explains that several efforts have been made in the research and development sector towards developing energy efficient machine tool. Inasaki et al. [2] have investigated that, to obtain energy efficiency in machine tools during machining operation reduce the use of cutting oil.

Dornfeld and Rangarajan [3] proposed that an efficient tool path with techniques of workpiece setup helps in monitoring of power consumption in machine tools. Diaz et al. [4] have explained that from spindle motors the regenerated energy can be reused. Neugebauer et.al., [5] have made evaluation through drilling operations on material removal rate and by changing cutting tools.

Electricity is the main source of power for the machine tools. In machine tools, spindle rotation and servo-driven axis motion are the power consuming elements. Machine tools, power consumptions are exceedingly reliant on cutting parameters. Additional power requirements come from the hydraulic unit, cutting oil pumps, cooling devices, and peripheral devices like the controller units. The power consumption from each of this equipment differs mostly by operating conditions. The key factor for reducing power consumption for metal cutting operation and other exterior devices movements is by reducing the cycle time. By switching off devices that are not in use during setup and/or minimizing intervals, energy consumption can be reduced. This concept was explained precisely in the research work by presenting suitable modifications to the work proposed by Fujishima et. al., [6]. A detailed survey was carried out on the recent work in the field of energy efficient electro-hydraulic system. Numbers of attempts were made to comprehend and incorporate fuzzy logic in the Electro hydraulic circuits in order to make the intelligent circuit more efficient. Nils Weinert et al. [7] have developed a methodology involving energy blocks for accurate energy consumption and

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production. The methodology is based on the representation of production operation and has sections of definite energy consumption for each operating level. Daeyoung kong et al. [8] have provided a software-based tool path evolution for energy efficient manufacturing. The presently available life cycle assessment tools have been replaced by a web-based application programming interface in which a rough estimation of the environmental impact of different manufacturing operations is omitted. Tsuneo et.al., [9] have discussed the possibilities of mechanical/electro-chemical/complex machining process for an efficient, precise and environmentally is a process. Kroll et al. [10] have discussed the overall influence of lightweight design methods on energy efficiency in machine tools and limitations on the mass reduction for structural machinery. It has a vital aspect, with different quantifiable consequences of energy consumption of lightweight structures of machine tools were designed.

Dynamic interaction of various procedures and auxiliary equipment's needs are to be considered, when developing and monitoring manufacturing systems.

Herrmann et al. [11] have discussed this concept on their work on energy-oriented simulations of manufacturing systems. The process and system approaches were followed by Joost R Duflou et. al., [12] proposed to make available a systematic outline in the direction of energy and resource efficient manufacturing.

A comprehensive literature review regarding energy efficient and sustainable manufacturing was discussed and the developments of energy efficient methods for green industrial operation were presented. The literature survey presented in this paper mainly focuses on energy efficient drives and control systems in machine tools.

The energy efficient control and drive technology can be a hydraulic drive, pneumatic drives, and electrical drive technology. In the present literature survey, Under the section drive technology in hydraulic circuits for energy efficiency, by optimizing the adaptation of control and drive technology, the present Work aims at incorporation of Electro-hydraulic system with an intelligent control system for elimination of unnecessary machine tool operations and hence resulting in optimized machine tool operation in leading to green industries.

Under the section Control strategies of open loop hydraulic system with a closed loop control system explains the concept of intelligent control strategies of electro hydraulic circuit. Also, there is a scope to bring the changes in the basic hydraulic system by installing a variable frequency drive, which decreases the energy consumption of the system up to 70 %. In order to increase the efficiency of the hydraulic circuit, an accumulator can be installed near the rod or piston end of the cylinder to avoid the pressure drop or leakage after the Directional Control Valve were explained in section Design modification in hydraulic circuits for leakage losses. The hydraulic circuit can be made even more efficient by making the circuit regenerative along with the installed VFD power pack.

II. Drive Technology in Hydraulic Circuits for Energy Efficiency

A Power Assist Unit (PAU) centered on the variable speed drive (VSD) principle to overcome the poor response and low accuracy of the variable speed electro-hydraulic system caused due to large inertias of the motors and pumps were proposed by Ming Xu et. al., [13].

The authors have suggested PAU was nonlinear multiple inputs and multiple output system due to which state-space model was introduced. After the experiments were carried out the authors found that bigger the size of the accumulator better would be the performance, also the power consumed in PAU based system is less compared to the traditional system. It was also seen that PAU based VSD can gain better speed tracking error in comparison with the traditional Variable Speed Drives.

Arun Shankar et.al., [14] have suggested various control techniques on direct torque control (DTC), which was systematically analyzed with Permanent Magnet Synchronous Motor (PMSM) attached to a centrifugal pump. In consideration with the stator current ripple and stator flux ripple, DTC with space vector modulation (SVM) gave a better result. Torque ripple was also reduced in his approach. It was also observed that by the implementation of DTC-SVM flow rate and pressure were increased at the same time. A novel energy system to reduce energy consumption and increase the working efficiency of the hydraulic press was discussed by Lei Li et. al., [15].

The experimental setup had two actuators linked with pipes and valves to synchronize the falling practice by one actuator to the returning process of another. The authors witnessed that by this method the energy consumption can be minimized by around 20.61% and increment in working efficiency by 26%.

Devendra Pal Singh et. al., [16] have conducted experiments on incorporation of variable frequency drives with a 150W induction motor, without any load on the motor at different frequencies like 40Hz, 50Hz, and 60Hz.

At the end of the experiments, authors have observed that the output power decreases as frequency decreases. Through the experiments carried out by the authors, it was also observed that 26.93% power has been saved by decreasing the frequency from 50Hz to 40Hz.

Priyanka Patnaik et.al., [17] have studied an induction motor with and without variable frequency drives for a pump based system on their experiments. The authors have come to the conclusion that VFD is the only method to control the speed of an induction motor. It was noted that a VFD controlled motor consumes as much as 6 times lesser power than the traditional system. V. K. Arun Shankar et.al. [18] have experimented for energy saving model and introduced the fuzzy logic concept of Variable frequency drive which controls the pump speed.

Fig. 1 shows the system which is using the pump drive. By experimental statistics, the authors have concluded that a design of the components and system dimension plays a major role in energy saving model.

Also, authors have found that nearly 30-50% of energy can be saved using intelligent control technique.

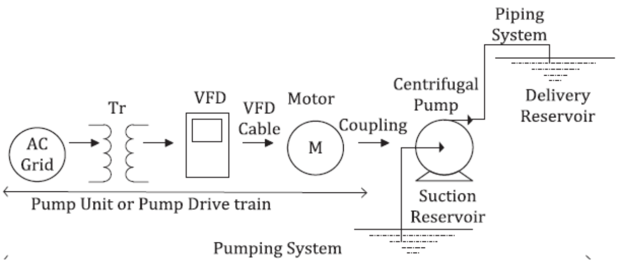

Fig. 1. System using pump drive

A multi-pump station to work in the best efficiency region, predictive control methods have been proposed by IljaBakman et.al., [19]. The authors have proposed a circuit in which each motor is connected to VSD which is altogether connected to the PLC system. Fig. 2 explains the typical structure of a multi-station pump.

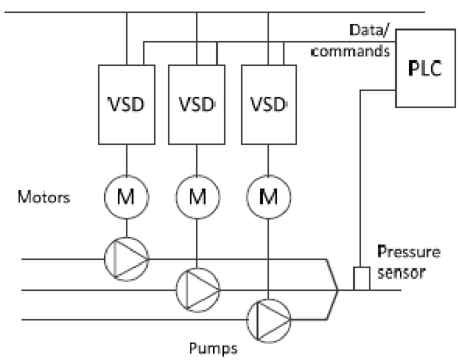

Fig. 2. Multi-station pump's typical structure

Authors have also developed an algorithm for automatic prediction and decision making. Speed control of a pump plays an important role in obtaining the energy efficiency of the system.

Chun-Lien Su, et.al., [20] have carried out research on the energy saving study model for variable-frequency controls on seawater cooling pumps on ships. Through their experiments, the authors found the temperature of seawater plays a vital role in energy saving. Authors have proposed a method for efficient and quick evaluation of seawater cooling pumps on ships with different routes through which the advantages of the energy savings using variable-frequency control. Peng Wu, et.al., [21] have achieved maximum efficiency by defining the enhanced schedule of a parallel pump system. For accomplishing less consumption of energy, the authors have used a Genetic Algorithm (GA) which focuses on increasing efficiency. The optimization of two indistinguishable pump processes was verified using GA was explained theoretically. Fig. 3 shows a P-Q curve at a different operating condition. Besides conserving energy, the main aim is the application of variable frequency electric drive of pump pressure which acts a major role in saving energy. A. Krylov, et.al. [22] have presented a closed circuit of pressure regulated block diagram. Fig. 4 explains an algorithm for the energy saving model using control of the electric drive pumps.

Authors have also recommended the adjustment of the regulator. And they have focused on an improved algorithm for a cold-water supply system by adjusting the pump for water consumption.

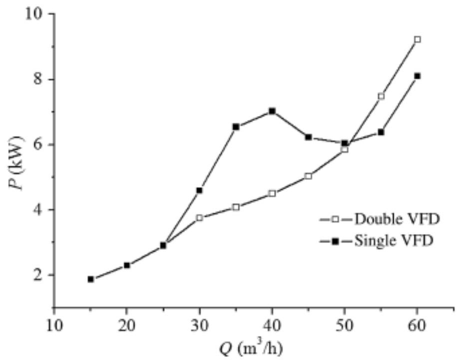

Fig. 3. P-Q Curve at different operating conditions

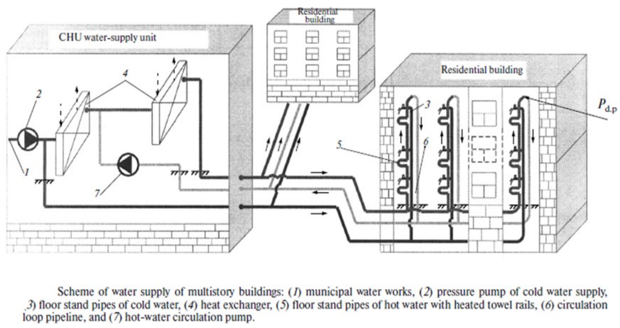

Fig. 4. An algorithm of control of the electric drive of pumps for energy saving

Ming Xu et.al., [23], have worked on an innovative drive principle which includes both accumulator-based power-assisted unit (PAU) along with the variable-speed valve-controlled motor drive. Power Assisted Unit helps in improving the precision control and response of the proposed drive which is compared with variable speed drive. Fig. 5 explains the system with a power assisted unit driven by the variable speed valve-controlled system. Comparing the simulation result with the existing variable-speed drive system the authors have found that the projected model exhibits good performance. This concept not only helps in achieving expected energy saving, but it also helps in improving the precision control and response. M. Deepa [24] has worked on how a variable frequency solution can be employed using VFD with a pulse width modulation technique.

This technique is appropriate for crisp control of motors with VFD, like timers and sun lamps. In industries VFD controlled motors are used which leads to higher energy saving. In district heating stations flow rate modification with variable-speed pumps which is a beneficial technique in the water pumping system. A relation among the heat demand and water discharge was assured and gaining energy savings that can be as high as 50%.

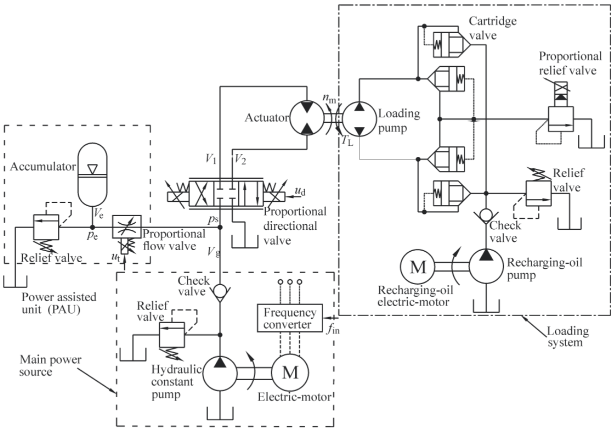

Fig. 5. System with a PAU driven by a variable speed valve controlled motor drive system

Ioan Sarbu et.al., [25] have concluded that the variable frequency drives are the best solution for varying the pump speed because these are connected between the energy source and electric motor and set for the explicit requirements. Lei Li et.al., [26], by their analysis, got the conclusion that, if a hydraulic press is used in the forming process along the conventional drive, only 27% of energy is utilized in forming operation and idle motors consume energy up to 40%. The mismatch between demand and the installed power leads to lower efficiency, which is caused due to the increase in energy consumption during the ideal run. Upon this study for a hydraulic press, an energy saving method was proposed by Fabian Papa et.al., [27]. The authors have set a benchmark i.e., Pump energy indicator (PEI) metric which helps in identifying the amount of energy consumed by the pump to deliver flow and pressure for its entire range of operation. The changes in the operating protocols along with the intrusions such as replacement of impeller or pumps were supported.

Markus I. et.al., [28] have developed a tool that provides interesting insight into pump battery working behavior, such as the available working regime, specific energy usage, and efficiency. The study shows that the tool efficiency is equivalent to the values measured from VSDs but adjusting the pump battery control can save 5–10% of energy. Comparing the traditional on-off control versus the innovative VSD control system is explained by Maurizio Faccio et.al., [29]. The authors have focused on contrasting economic and environmental convenience. From a global point of view, the authors have analyzed the environmental benefits derived from retrofitting the existing industrial systems through VSD technology, especially in developing countries.

Introducing a systematic methodology for structured analysis of a pump system to explore and evaluate potential solutions for energy efficiency improvement, S. Sajjad et.al., [30] have focused on this concept. Through experimental studies, the authors have found that the impeller trimming or changing impeller size with minimum tip diameter for the existing pump can make an oversized pump work more efficiently.

III. Control Strategies of Open Loop Hydraulic System With a Closed Loop Control System

Arun Shankar et.al., [31] have designed the Direct Torque Control (ANSI-DTC) based on Neuro-Fuzzy Inference System for Permanent Magnet Synchronous Motor (PMSM) coupled to a centrifugal pump. The proposed intelligent system was used to cut the ripples in torque and increase the response. The experiments and simulations also confirmed that ANFIS-DTC improves the performance of the drive with enhanced flux and torque control capability. ANFIS-DTC also resulted in smooth pressure output in pumps compared to conventional DTC and DTC with Fuzzy logic control.

Volume control servo-hydraulic press, driven by Switched Reluctance Motor (SRM) was developed by Jian-Ming Zheng et. al., [32]. Considering the nonlinearity, time variability and time delay in the current SRM direct drive volume control system, a fuzzy PID control technique was explained. The results explained that the time delay which was present in the hydraulic system had a huge effect on the closed-loop control system. The fuzzy PID controller had solved the conflict between response frequency and overshoot which enhanced the control accuracy and capability to restrain external disturbance. Thus, making the fuzzy PID controller is the finest option for SRM direct drive volume control hydraulic press. An active closed-loop control method for the stepper motor, this method consisted of motor parameter identification, current control, position control, and damping control. It accomplished precise situation, high torque, and smooth speed. The better PI current control algorithm was used to assure current tracing performance and also raise the bandwidth during the speed response. This also attains high torque and functioning of stepper motor was enriched. The motor functions effortlessly over a varied speed range. The speed performance with this technique is perhaps better than the lead angle technique specifically for low and very low speed ranges according to the authors, Kien Minh Le et. al., [33]. Pei Lei et.al., [34] had suggested a technique in which assembly lines of large-scale components can be machined. Step-NC was proved to perform brilliantly in data interchange from CAD/CAM to CNC but it doesn't help some different process in machining the assembly interfaces for solving this issue a closed loop machining system based on extended step-NC data models with supporting and laser tracker measuring process was introduced. The result of this technique was that it had tight control of machining quality and increased working efficiency. Shengyushi et.al., [35] have developed a model of feed drive with backlash from a fully closed loop feed drive.

The proposed model was used to study the transient backlash error. The author had installed built-in encoders, which helped them in proposing a sensor-less measurement technique to recognize backlash width. G Stan [36] has proposed a novel system for reducing mechanical backlash, based on the direct type of cylindrical gearings with tapered teeth, accepting backlash alteration between the flanks of the teeth joint.

The proposed system provided a safe and ingenious adjustment of backlash between flanks over the controlled axial movement of one of the two gears that composes of the gearing. It also allowed the adjustment of the backlash between the flanks by involving the outside of the reducer housing. A redesigned and modified electro-hydraulic servo position control system that was controlled by the fuzzy PID controller was proposed by Zhixing li et. al., [37]. When the comparison was done with the traditional PID controller it was found that the fuzzy PID controller had better precision and faster response speed when tracking step signal, sinusoidal signal, and simulated movement. Keiven Baghestan et.al., [38] have proposed an energy conservation approach for electro-hydraulic systems. The main idea during the operation with the help of a proportional relief valve is to minimize the Pump pressure. The position control task was done by the proportional direction valve with back-stepping strategy.

An outline and execution method of real-time machining process control depending on the STEP-NC was offered by Po Hu et. al., [39]. The author had chosen reduction of cutting force at the specific direction of machining feature inside the mill. Later a fuzzy control algorithm was used with self-adjusting factor was designed and embedded. In the results, the authors have indicated that the STEP-NC controller was able to interpret a STEP-NC file with real-time machining process control functions correctly and keeps the cutting force at a specific direction close to the ideal value. Mete Kalyoncu et. al., [40] have described a fuzzy logic position control to an electro-hydraulic servo system bearing in mind the internal leakage. The paper also presented mathematical modeling and fuzzy logic-based position control of an electro-hydraulic servo system. A direct-drive electro-hydraulic servo control system mathematical model was developed by Yulin-Ke et.al., [41]. Later by providing varied signals, the control features of the direct drive electro-hydraulic servo control system were analyzed using PID and fuzzy PID control. The results showed that there were severe delays and large overshoot between system output and control targets when PID controller was used, a conflict between system stability and fast response were difficult to resolve, whereas intelligent fuzzy PID control could resolve all this. The high regenerative potential is available in rotational loads such as excavators or winch systems. Based on the closed-loop hydrostatic transmission, Triet Hung Ho et.al., [42] have developed an innovative hydraulic energy-regenerative system with the use of a hydraulic accumulator as the energy storage system to gain back the kinetic energy without the reverse flow of the fluid. Figure 6 shows a Schematic diagram of the test bench. In the secondary unit, the displacement variation was brought down. To control the speed of a secondary unit an adaptive fuzzy sliding mode controller is used. Experiments and simulation were performed. The experimental results clearly show that the system design was very efficient and the round-trip retrieval efficiency varied in the range of 22% to 59%. Round-trip efficiency of the system measured is shown in Fig. 7.

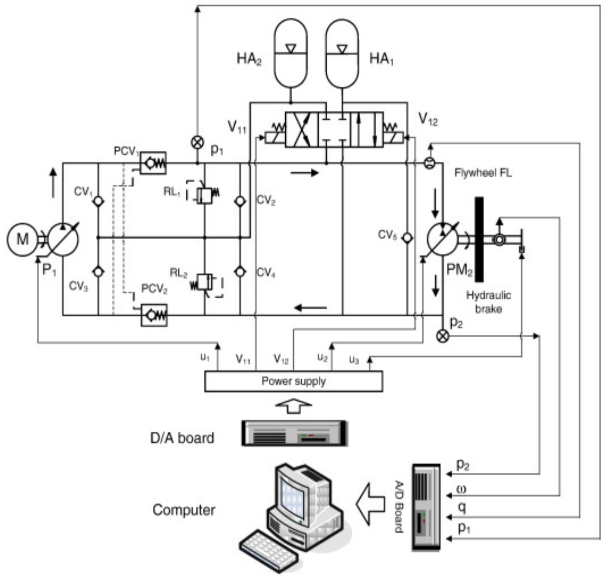

Fig. 6. Schematic diagram of the test bench

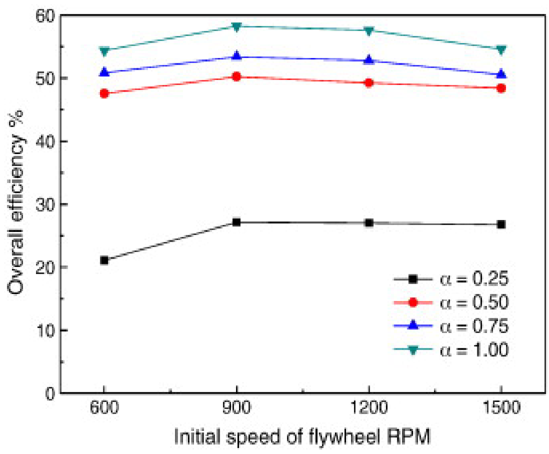

Fig. 7. Measured system round-trip efficiency

According to Alexandra Brogan et.al., [43], 10% to 20% of the world's electricity is used by pumps and up to 60% of them are not efficient. Bypass flow should be minimized or eliminated to maximize the energy saving in a variable flow pump. The ideal way of minimizing or eliminating is by using two-way bypass valve or primary-secondary pumping. Also, VFD speed controlling is done by locating a differential pressure sensor at certain points of the system and Δp set point should be as low as possible. Sami Kukkonen et.al., [44] have discussed Pole placement techniques. This is later simulated and is compared with a system using dynamic pressure feedback. The obtained result shows the enhancement of the actuator response damping level, but also increases the need for displacement range and pump torque. High accuracy hydraulic pressure variation was proposed by Chen Lv et.al., [45] to control a switching valve based on a linear pressure drop. Based on the dynamic hydraulic brake system model with valve dynamics, linear relation between the coil current and pressure was theoretically illustrated and was verified later. However, the proposed modulation was sensitive to structure parameters and environmental temperature changes. Hence to achieve better results, more robust and precise modulation was done, a gliding mode controller based on a closed-loop algorithm scheme was advanced.

The performance and effectiveness of the modulation were compared with the existing controls. Many parameters are to be checked in the ship boiler in order to decrease the wear and tear of the pump and the boiler. Chun-Lien Su et.al., [46] have compared the use of PID and VFD in marine boilers to control and check the safety and parameter that should be considered in the ship. According to the tests carried out by the author, VFD driven constant pressure feed water regulator can handle all the performance requirements and can avoid pump overload trip, which indirectly increases the safety of the electric motor. Further overhaul of pumps can be reduced by a greater extent. Fig. 8 shows the proposed hydraulic circuit.

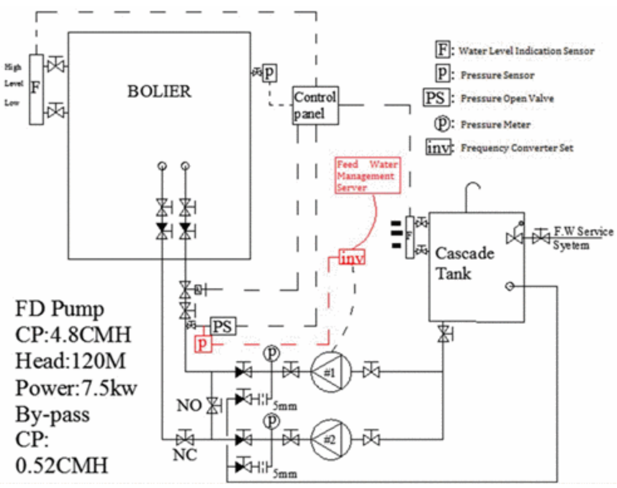

Fig. 8. Scheme of the proposed control system

Most of the pumps used in industries are oversized than the duty they perform and are throttled at the output according to their requirement. This reduces the efficiency of the pump. Rajendra Kumar Patel et.al., [47] mention that efficiency can be increased by adjustments made to the rotation speed. This can be achieved by using VFD. Through experimentation and simulation, the author concludes that the use of VFD can reduce the power consumption by 25% by reducing the 10% operating speed of the pump. In a CNC machine, the tool for a servo system can be briefed as high accuracy, well firmness, quick response and so on. On basis of the smart fuzzy controller, Chen Yang et.al.,[48] have developed a PID controller of a feed servo system. Figure 9 shows the structure figure of the smart fuzzy PID controller.

According to time-changing working situations, arithmetic's main feature is to change parameters in different degrees. Variable frequency induction motor driven hydraulic source have a lethargic response, poor governor precision, easy to overshoot.

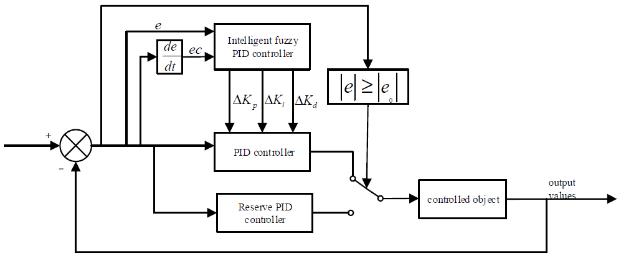

Fig. 9. Structure figure of the smart fuzzy PID controller

An innovative hydraulic power source was developed by Ma Yu [49] using a gear pump which was driven by a permanent magnet servo motor. The main benefits of this hydraulic power system are energy saving and rapid response. The paper presents a smart neural grid control scheme which combined fuzzy inference, neural grid adaptive and simple PID control benefits. Figure 10 shows the hydraulic system control structure diagram.

From the simulation, the author concludes that for both static and hydraulic load the developed method has decent response speed and control precision. Accurate positioning is crucial in the machine tool industry and here nonlinear phenomenon must be considered.

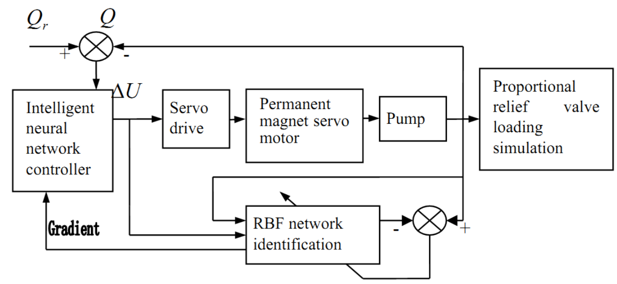

Fig. 10. Structural figure of a hydraulic control system

Nur Amira Anang et.al., [50] have done a significant review of machine tools and authors have discussed based on dead zone phenomenon and high bandwidth. Later linear control strategies are reviewed which involve PID and cascaded P/PI controller. Also followed by nonlinear control strategies, Feed forward NPID (FNPID), Adaptive NPID (ANPID), Adaptive Robust Controller (ARC), Nonlinear PID (NPID), Nominal Characteristics Trajectory Following (NCTF) controller and lastly, the fuzzy and neural network control is then reviewed. Conclusions are made according to past research. An improved particle and optimized algorithm are developed by Y. Ye, et.al., [51] to tune the gain obtained from the PID controller in order to cope with the position control problem of cylinder system used in an excavator. Nonlinearities derived from physical modeling are later simulated with three different position references. Also, comparison of tuning methods shows the superiority of improvement in PSO algorithm. Figure 11 shows the pressure vs time graph.

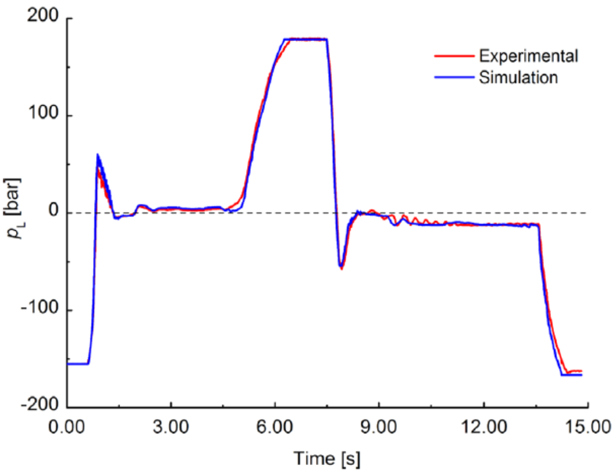

Fig. 11. Pressure vs Time

AC motors run at constant because it consumes the rated power from a supply and hence creates a problem when less motor speed is needed. S. Tonapi et.al., [52] has discussed the use of VFD in speed control of AC motor. Also, the working principle of VFD is understood.

Simulation and experimental verification of VFD based centrifugal pumps were experimented by Vishnu Kalaiselvan Arun Shankar et.al., [53]. The performance of VFDs based system and pumping action at different speeds was studied with the experimental results.

IV. Design Modification in Hydraulic Circuits for Leakage Losses

To advance the performance of the engine in terms of the volumetric efficiency, power output, emission, and consumption of fuel Variable Valve Actuation (VVA) system can be used. Mohammad Pournazeri et.al., [54] have designed an innovative VVA system. In this proposed system, hydraulic cylinder actuated by two rotary spool valves actuates the engine valves. This type of valve system has the capability of variable valve timing and valve lift at various speeds of an engine.

Controlling difficulty, low reliability and sluggish response of the actuator can be eliminated, which is present in the existing cam-less valve train. The difference in opening and closing timings of valve and lift of valve was examined by computing the standard deviation of the experimental data recorded over a trial run of 80 cycles and the results exhibited a standard deviation which is less than 90 µm for the valve lift and 2.5CA°at an engine speed of 2000rpm. The braking energy can be recuperated which can be used as a power pack for an efficient hydraulic drive system present on mobile equipment. The proposed system is incorporated into a current application, an Isuzu truck which uses the hydraulic system to collect the garbage. L. Pugi et.al., [55] have designed a prototype which is then assembled and tested for various parameters and it has been found that system efficiency has increased and so the feasibility of the work. Simulations clearly show that the amount of energy harnessed from the system is sufficient to feed the hydraulic system and any extra electrical consumption can also be fed by the recovered energy. To operate the system under high-pressure conditions various design techniques, tribological properties, and manufacturing techniques have to be enhanced. Ihn Sung Cho [56] have studied the optimum design factors that satisfy the requirement of the system at high pressure and stress distribution on the valve plate. From the experimentation, the authors have concluded that the valve for the maximum stress of the enhanced model is found to be 13.3% lower compared to the previous standard model.

Also, it can be seen that the maximum stress value of the enhanced model is found to be 23.9% below of yield strength. So, the design specifications of the optimized model can be applied to the models whose discharge pressure exceeds 40 MPa. Sung Kim et.al., [57] have devised a numerical study to enhance the performance of a mixed flow pump using CFD code and DOE by adjusting design factors of the impeller and diffuser.

From the analysis, it can be seen that Ht was affected by the exit part design variables and ηt was affected by inlet variables. From the numerical study, the ηt of the optimized model improved by 2.67% and the Ht of the optimized model was enhanced by 3.73m when compared to the basic model. A test rig was developed by Shankar Bhaumik et.al., [58]. The authors have experimentally analyzed the various reciprocating hydraulic seals perform.The test rig has the capability to study the contact phenomena at the sealing interface and compare with the theoretical values. So, it will help in developing a new sealing system which can be used for shock loading applications working under a pressure of 1000bar. The test rig also possesses an additional feature to do the experimentation at high pressures and also under shock/cyclic loading. A solution to minimize the energy losses at compensators was found by Jan Siebert et.al., [59]. An additional hydraulic circuit is used to increase the pressure of a particular section. Pressure level at the compensators is increased by connecting a retrieval unit connected in series with the hydraulic accumulator through a special valve. By doing so the amount of hydraulic power to be throttled is reduced.

The loss in pressure at the respective pressure compensators can be reduced, till the section fulfills the swapping condition of the valve. Extra energy can be renewed and can be sent to different processes via a suitable recovery unit. An AC servo motor drives a closed hydraulic control system used to control a spiral swinging hydraulic cylinder is designed by Ye HUANG et.al., [60]. Design parameters and structure of the spiral swinging hydraulic cylinder were analyzed and calculated. As per the control system's needs, the speed of the servo motor is adjusted by a hydraulic system, and the motor power matches with the power supplied to apparatuses. Thus, loss due to throttling in hydraulic circuits is eliminated.

Alexander Wohlers et.al., [61] have presented an approach to optimize the hydraulic reservoir through experimental and numerical analysis to resolve the challenges faced in designing of hydraulic reservoirs.

Various numerical methods are used to study the performance of hydraulic tanks. To study the cooling capacity of hydraulic tank heat transfer analysis is used. In order to support the numerical methods, experimental setups are built to confirm the results obtained in the simulation and to provide extra help to design and optimize the hydraulic tanks. Philipp Hedrich et al., [62] have presented a compact hydraulic linear actuator. The actuator is designed such that it should move a little at higher forces. An actuator is not sensitive to forces acting on sides induced by the bellows which roll on the rolling piston in the air spring. In order to minimize the friction diaphragm sealing is used. Accurate displacement adjustments can be made and the arrangement is leak proof even at higher speeds. It is possible to incorporate assembly of the valve which has 128 min valves, which can be used as an alternative to the conventional CETOP3 proportional valve. MattiLinjama et.al., [63] have built a model and studied experimentally and from the results, authors have concluded the performance of this type of valve system is highly reliable than conventional four-way DCV considering the time of response and fault acceptance.

V. Conclusion

Improved management of energy efficient system and design of the electro-hydraulic system may contribute to the inexpensive operational cost. This design has an energy efficient hydraulic circuit which is for various applications in machine tool industries like Clamping, Automatic pallet changer etc. It is suggested to implement the design and develop a closed loop Electro-hydraulic circuit for improving the energy efficiency of a hydraulic system along with the Modeling and simulation of a hydraulic circuit for studying the pressure flow profile, power consumption by implementation of energy conservation strategies using Variable Frequency Drive and Regenerative concepts for testing and validation of proposed hydraulic circuits.

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