International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8, Issue-1, May 2019

Modelling and Simulation of Electro-Hydraulic Circuit used in Hydraulic Power Pack of A CNC Machine Tool

Ramesh. S, S. Denis Ashok, Shanmukha Nagaraj

Abstract: Electro-hydraulic systems are widely used in machine tool industries. Energy saving has become the need of modern machine tool industries, as the significance of energy conservation is more prominent by industrial economists. Insignificant increases in efficiency in an electro-hydraulic system will have a substantial economic impact on the total cost. The electro-hydraulic system comprises of auxiliary components and different motors whose energy consumption can differ intensely during machining operation. A comprehensive analysis of the energy utilization can be calculated for an electro-hydraulic circuit and the chances of energy saving in an electro hydraulic circuit are modelled and simulated for the proficient use of energy. This research paper focuses mainly on Modelling and simulation of electro-hydraulic system used in a CNC machine tool by the incorporation of a variable frequency drive for energy efficiency. Simulation results show the prospective improvement in energy conservation.

***Index Terms*: Electro-Hydraulic system, Energy efficiency, modeling and simulation, Variable frequency drives, CNC Machine.**

I. INTRODUCTION

The words "Energy Efficiency" refers to less energy consumption to deliver the matching amenity. The best way to know this concept is through examples: if a person replaces an only window in a house with an energy-efficient window which holds the warmness inside the room and prevents it from escaping in the winter, in turn saving energy whilst staying comfortable. This efficient window retains the heat, during summer, so that, the air conditioner will not run as frequently and in turn saves energy. When one can replace an appliance, such as a refrigerator, washing machine, computers with some additional energy-efficient components, the innovative equipment delivers a similar facility by consuming less energy. This reduces the percentage of greenhouse gasses going into the atmosphere and helps to reduce the monthly energy bill. Increasing request for reducing energy consumption by a limited source on the world market results in nonstop increasing in price of energy. In the consumer market, energy efficiency and energy consumption are gaining importance's as a substantial feature in machine tool industries. The modern survey explains towards developing energy efficient machine tool, that numerous efforts have been made in the investigation. Inasaki et. al.,

[1] researched that, during machining by reducing the use of cutting oil gives the energy efficient manufacturing in machine tool industries. Dornfeld and Rangarajan [2] explained that a competent tool path with workpiece arrangement and observing the machine tools energy consumption. Diaz et. al., [3] explained the concept of reprocessing the regenerated energy. Neugebauer et. al., [4] have assessed the material removal rate through drilling operations by replacingthe cutting tools. For the machine tool, electricity is the main source of power. The energy consuming elements in machine tools are servo motors and spindle rotation. energy usage is dependent on cutting parameters of machine tools. Hydraulic unit supplies the supplementary power requirements.

The model ofenergy saving is clarified by V K Arun Shankar et.al., [5] by introducing the concept of fuzzy logic controllers. The pump speed was controlled by variable frequency driveswhich was also modeled and simulated. By the experimental statistics, authors came to a conclusion i.e., system performance plays a major role in energy saving by design of the components and found out up to 30-50% of energy can be saved. Ilja Bakman et.al., [6] have carried out the work on this method.

Through the experimental studies, Simulation model and results, the authors recommended a hydraulic circuit in which each motor is coupled to variable speed drives which are attached to PLC's. Regulating the speed of a pump plays an important role in the better management of electric energy efficiency. Chun-Lien Su, et.al., [7] have proposed a study model of energy saving for variable-frequency controls.

By the operating conditions, the power consumption differs from each of those equipment. By reducing the cycle time the consumption of power can also be reduced in a material removal process and other machine tool arrangements. Fujishima et. al., [8] have justifiedspecifically in the investigation by showingappropriatechanges on energy consumption, which can be reduced by switching off devices that are not in use during setup and/or reducing intervals.

Conservation of Energy of machine tools has turned out to be the most significant topics on account of expanded costs of fuel, which is desired to save the ecosystem. The vibrant performance is better when associated with electrical-mechanical systems [9].

Revised Manuscript Received on 22 May 2019.
***** Correspondence Author
Ramesh S,School of Mechanical Engineering, VIT, Vellore, India
Denis Ashok S, School of Mechanical Engineering, VIT, Vellore, India
Shanmukha Nagaraj, Mechanical Engineering, R V College of Engineering, Bengaluru, India.

Hydraulic systems during the loading cycle that use several hydraulically functions like a cylinder, actuator as a hydraulic motor may have a number of operations simultaneously like automatic tool changer, clamping, cutting, drilling, and many more consumers power. Hydraulic power mainly depends on load during the high or low speeds of a cylinder or hydraulic motor [10].

A traditional hydraulic circuit driven by constant speed hydraulic pump operating at 1450 rpm is typically used. During the period of idling using 30-45% of the full load amperage the motor operates at full speed [11].

II. HYDRAULIC SYSTEM

The term "hydraulics" commonly denotes power produced by moving liquids. The hydraulic control system is a system to control an actuator (an actuator is a mechanical device, which can be set in motion and the so, set motion, is controlled with the hydraulic system). The hydraulic structure is an assembly of hydraulic elements are organized in order and using these elements hydraulic power is transmitted using a confined fluid i.e., hydraulic oil. Hydraulic force in the form of pushing, pulling, rotating, regulating and driving.

A philosopher from French by name Blaise Pascal has explained that liquids are incompressible. Pascal'slaw explains that "Pressure applied to a confined fluid is transmitted in all directions with equal force on equal areas". Figure 1 shows how Pascal's law is applied to a confined fluid.

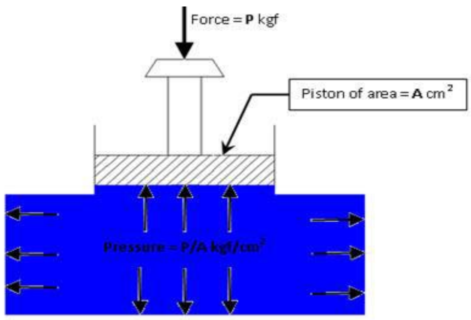

Fig. 1. Pascal's law illustration

III. COMPONENTS OF A HYDRAULIC SYSTEM

A fluid system that uses hydraulic oil is called a hydraulic system. Hydraulics produces forces and transmits motion by means of hydraulic fluids. The hydraulic fluid signifies the medium of power transmission. Hydraulics deals with power transmission control of mechanical motions and characteristics of fluid under pressure. The hydraulic system uses pressurized hydraulic Fluids (normally oil). The heart of the hydraulic system is the pump that pumps the pressurized fluid into the system. Hydraulic oils are supplied to a cylinder, which converts it to a linear force and displacement [12].

A hydraulic system containing key components shown in figure 2. has a tank or reservoir contains hydraulic oil, pump used to post the liquid over the system, an electric motor to drive the pump, an actuator (normally a double acting cylinder) used to change the energy of liquid into mechanical force or torque to do the suitable work, for controlling the direction of fluid flow different types of valves are used, pressure and flow rate of fluids, fluid lines to carry the hydraulic fluid from one place to another. The system as a whole is known as Hydraulic Power Pack as it is the powerhouse for performing all the application. The hydraulic power pack in CNC machines are used for various applications like Tool clamp / de-clamp operation, Pallet clamp / de-clamp operation, Hydro motor for arm rotation or turret rotation, Automatic Tool Changer, Rotational axis clamp / de-clamp operation [13].

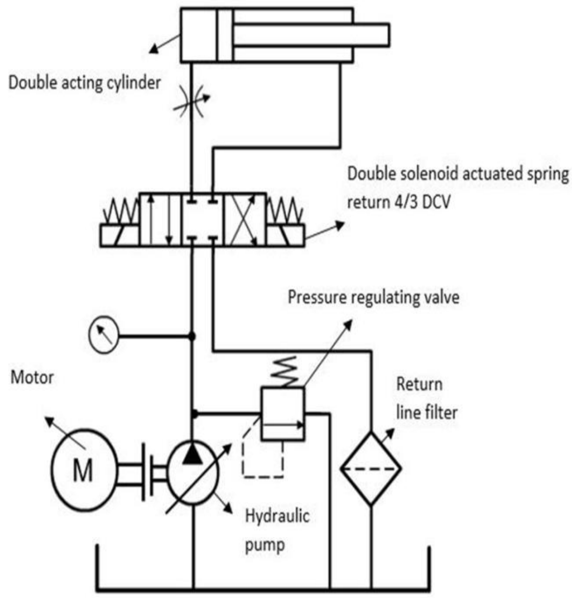

Fig. 2 Hydraulic system containing key components

IV. MATHEMATICAL MODELLING

To the non-linear modeling, Fluid mechanics and advanced mechanics were applied, exactly the law of Conservations of energy and mass to the fluid and Newton's second law of motion for the loading. The simple equations were used to define the performance of a hydraulic system.

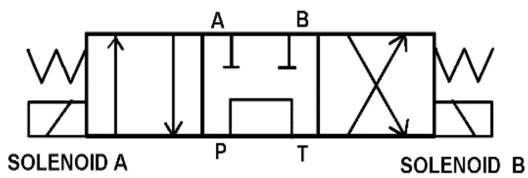

Fig. 3. 3-position, 4-way Direction Control valve

For double-acting, cylinder requires a ¾ way direction control valve. Figure 3 represents a 3-positions and four-way direction control valves as P=pressure port, T=Tank Port, A= Aside inlet port of double acting cylinder normally cap end side of a cylinder for extension stroke, B= B side port of a cylinder generally cap end side of a cylinder for retraction stroke. Three positions of a direction control valve refer to operation positions which are represented as a square block. And these positions get actuated by the help of solenoid and spring return.

The equation for the movement of the piston is written in equation (1)

$$(P_A - A_A) - (P_B - A_B) = M_1 . \frac{d^2x}{dt^2} + Bc. \frac{dx}{dt} + F_{at} \quad (1)$$

By using the mass conservation equation, the inflow and the outflow from the chamber can be written as shown in equation (2)

$$q_{va} = A_A \frac{dx}{dt} + \frac{V_A}{\beta_e} \cdot \frac{dP_A}{dt}$$

$$q_{VB} = A_B \frac{dx}{dt} + \frac{V_B}{\beta_e} \cdot \frac{dP_B}{dt} q_{VB} = A_B \frac{dx}{dt} + \frac{V_B}{\beta_e} \cdot \frac{dP_B}{dt} \quad (2)$$

The effect of pressure on the control orifices shown in equation (3)

$$q_{VA} = Cd.A_3.\sqrt{\frac{2}{\rho}.(P_S - P_A)} - Cd.A_4.\sqrt{\frac{2}{\rho}.(P_A - P_R)}$$

$$q_{VB} = Cd.A_6.\sqrt{\frac{2}{\rho}.(P_S - P_B)} - Cd.A_4.\sqrt{\frac{2}{\rho}.(P_B - P_R} \quad (3)$$

Using total flow coefficient, the flow through working ports is explained in equation (4)

$$q_{VA} = K_v.\frac{U}{U_n}\sqrt{\Delta p_t}$$

$$q_{VB} = K_v.\frac{U}{2U_n}\sqrt{\Delta p_t} \quad (4)$$

The hydraulic oil output flow of hydraulic can be expressed in Equation (5)

$$Q_p = \frac{\omega.V_{th}}{2\pi} \cdot \eta_{vol} \quad (5)$$

where Q_p is represented as hydraulic pump output flow in m3/s, ω - rotation angular speed, V_{th} - pump theoretical volumetric displacement in m3/rev, and η_{vol} - volumetric efficiency [14].

The pump shaft differential equation is expressed in equation (6)

$$J_p \frac{d}{dt}\omega + T_{f,p}(\omega) = T_{motor} - \eta_{vol} T_{p,th} \quad (6)$$

where $J_{p,}$ - total equivalent inertia, is $\frac{d\omega}{dt}$ - pump angular acceleration, T_{motor} - drive torque, $T_{p,th}$ - theoretical torque for compressing a fluid, $T_{f,p}$ - frictional torque, η_{vol} - volumetric efficiency of the pum. To compress the fluid, theoretical torque can be demonstrated as in equation (7)

$$T_{p,th} = V_{th}(p_s - p_{rtn}) \quad (7)$$

where V_{th} - theoretical volumetric displacement, p_s - system pressure, and pm - tank pressure in Pa.

In an induction motor, the relationship between the frequency of the voltage source, rotor speed, number of poles and slip are expressed in equation (8)

$$n = \frac{120f_1}{P} \cdot (1 - s) \quad (8)$$

where n represents the speed in rpm, f_1 represents input voltage frequencyin Hz, Prepresents the pole numbers, and s represents the factor of slipin an induction motor. constant frequency constant amplitude voltage can be converted in to an adjustable frequency and adjustable amplitude voltage by inverters. The difference in the input frequency of the power supply hints to the speed of the machine.

In an induction motor, the torque developed is expressed in equation (9)

$$T = k_1 \cdot \emptyset_m \cdot I_2 \quad (9)$$

The magnetizing flux can be obtained as per Equation (10) based on the voltage drop caused by the stator impedance.

$$\emptyset_m = k_2 \cdot \frac{V_1}{f_1} \quad (10)$$

From equation (9) and (10), T is represented as available torque on the shaft in N-m, $\emptyset_m$ is a magnetizing flux in Wb, $I_2$is rotor current in A depends on load, $V_1$is represented as voltage in statorin V, and by depending on the materialsk_1& k $_2$are constants [15].

V. DESIGN OF EXPERIMENT

The proposed hydraulic power pack is designed to consume a lesser amount of power during the loading condition at a specified pressure. Pressure Relief Valve operates at 50 bar and Pressure Switch operates at 40bar

Frequency Converter Settings asthe Frequency Converter (FC) at 2 speeds controls the motor. Frequency-1 = 10 Hz with pressure = 40 bar and Frequency-2 = 50 Hz with pressure < 40 bar (This frequency is the input of AC current to the motor through the FC).

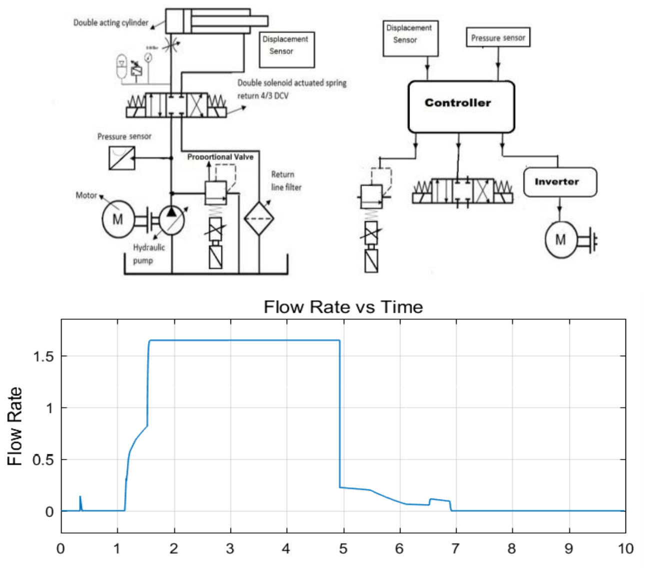

Fig. 4 Proposed Electro-Hydraulic Circuit

VI. DESIGN CALCULATIONS

The specifications of the present hydraulic power pack used for experimentation represented in table-1.

Table 1 Specifications of Present Hydraulic Systems

Sl. No	Parameter	Specifications
1	Dimensions	W=540 x H =650 x D =625 mm
2	Weight	107.5 kg
3	Paint Coating	Blue RAL 5010
4	Pressure	50bar
5	Oil Tank	40L
6	Flow	8lpm
7	Voltage	415 V AC
8	Frequency	50Hz
9	Power	1.5 kW

VII. MODELING, SIMULATION OF PROPOSED HYDRAULIC CIRCUIT USING MATLAB

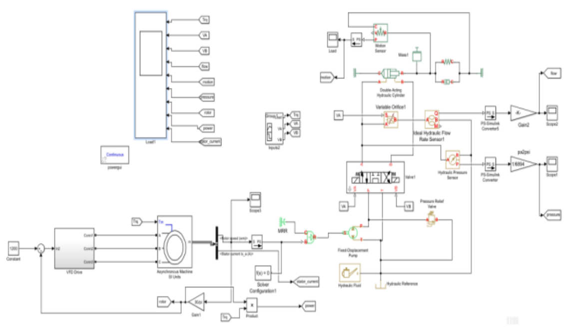

Fig. 5. MATLAB model of Proposed Circuit

Figure 5 illustrates the modeling of the proposed hydraulic circuit which is simulated in the MATLAB and the results obtained are mentioned below.

Pressure profile variation and consumption of power was examined. For the relative pressure profile results. The same results had been obtained for the present circuit. Hence, the pressure servo performance satisfies the complete pressure profile control and suitable increase in time might succeed reasonably for robust control.

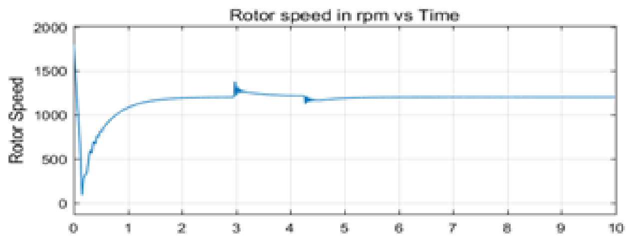

Fig. 6 Flow rate vs time

Figure 6 represents the flow rate in the Y-axis and time on the X-axis. When the piston is at the center position, there is no flow of oil and hence the flow rate remains 0. Then, after the actuation of the solenoid, the flow of oil in the circuit takes place and hence flow rate increases till the end of extension stroke and then there is very little flow or theoretically no flow. The minimal flow observed is used to compensate for the leakage losses.

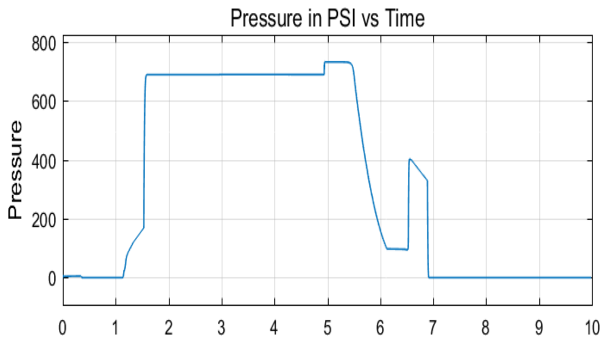

Fig. 7 Cylinder motion vs time

Figure 7 explains the cylinder motion during the operation. During the dwell condition, there will not be any flow of oil into the system so there is cylinder motion at all. Once the solenoid is activated there will linearly increase in the motion of cylinder till the end of extension stroke and a constant hold during the working cycle is seen. Later after the initiation of

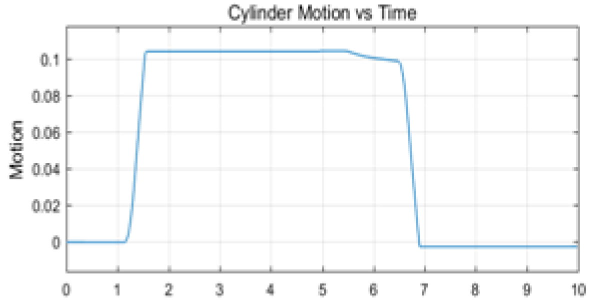

Fig. 8 Pressure vs time

Figure 8 illustrates the variation in system pressure. The pressure increases as the extension stroke initiate, once the piston reaches rod end then there is a slight increase in the

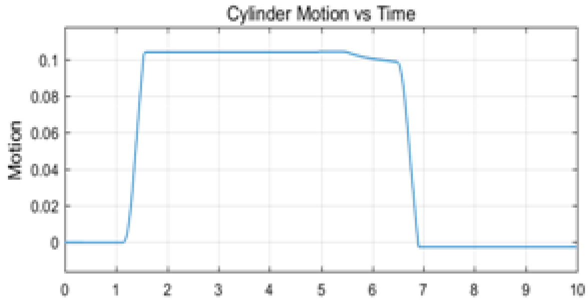

Fig. 9 Rotor speed vs time

system pressure which is seen in the graph and later the direction control valve is moved to the second position to cut the flow of oil in the system.

From figure 9, it is seen that the VFD can increase the minimum motor speed at a frequency of 50Hz. Primarily, the motor speed increases from zero and reaches just above the nominal speed [16]. It is very clear from the graph as shown in figure 10 that there is an extreme drop in the rotor speed initially and later there is a uniform increase and maintains the speed of around 1400 rpm throughout. This huge decrease in the rotor speed is due to the incorporation of variable frequency drive, which reduces the speed of the rotor when not required, which in turn is responsible for the reduction in overall power consumption of the system.

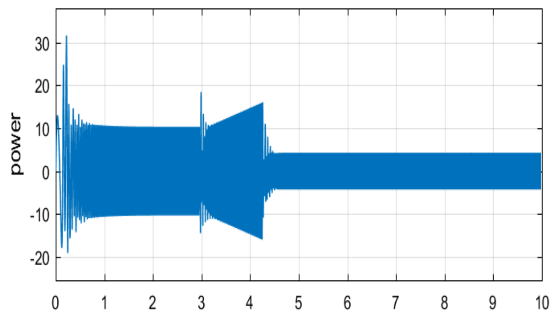

Fig. 10. Stator Current vs time

The simulation results of the proposed circuit with VFD which provides the advantages like energy conservation, Reduction of thermal and mechanical stresses on motors during starts, reduce in oil temperature, Optimum use of oil in the system. To equate the performance of energy utilization during the machine operating condition using both based on variable frequency drivers and existing electro hydraulic system.

To evaluate the operating performance of the system, the power utilization of the motors is used. Conventional system consumes 2.5kW of power whereas the VFD based Electro-hydraulic system consumes 0.54 kW of power. The present system reduces by 65% of the oil temperature in the reservoir. Whereas in the Proposed system, the flow rate of oil in the is just about 10% of that in the existing system.

VIII. CONCLUSION

Due to lack of feedback element in the existing hydraulic circuit, the proposed electro-hydraulic circuit is advantageous. Irrespective of the pressure variation in the circuit constant speed motor consumes more power than the proposed electro-hydraulic circuit. When the required pressure is reached, the variable frequency drive receives a signal from pressure switch which acts as a feedback element to reduce the Motor speed in turn which reduces the utilization of power. It can be observed that varying the frequency by 1 hertz varies the motor speed by 30rpm. Increasing the frequency rises the speed therefore, the flow rate and vice-versa. From the experimental results, it is found that the energy usage of the Present electro-hydraulic system is reduced by 78% and hence the system becomes economical. Therefore, The Energy saving potential of proposed Hydraulic Power pack used for CNC machine tool running by hydraulic systems with variable frequency drive is high.

REFERENCES

1. Weinert K, Inasaki I, Sutherland JW, et al. (2004) Dry machining and minimum quantity lubrication. CIRP Annals. 53(2): 511–537p.
2. Rangarajan A, Dornfeld D. (2004) Efficient tool paths and part orientation for face milling. CIRP Annals. 53(1): 73–76p.
3. Diaz N, et al. (2010) Machine tool design and operation strategies for green manufacturing. 4th CIRP HPC. 1: 271–276p.
4. Neugebauer R, et al. (2010) Modelling of energy and resource-efficient machining. 4th CIRP HPC.1: 295–300p.
5. VK Arun Shankar, Subramaniam Umashankar, Shanmugam Paramasivam, and Norbert Hanigovszki. "A comprehensive review of energy efficiency enhancement initiatives in a centrifugal pumping system." Applied Energy 181 (2016): 495-513.
6. Ilja Bakman, Levon Gevorkov, and Valery Vodovozov. "Predictive control of a variable-speed multi-pump motor drive." In Industrial Electronics (ISIE), 2014 IEEE 23rd International Symposium on, pp. 1409-1414. IEEE, 2014.
7. Chun-Lien Su, Wei-Lin Chung, and Kuen-Tyng Yu. "An energy-savings evaluation method for variable-frequency-drive applications on ship central cooling systems." IEEE transactions on industry applications 50, no. 2 (2014): 1286-1294.
8. Inamasu Y, Fujishima M, et al. (2010) The effects of cutting condition on the power consumption of machine tools. 4th CIRP HPC. 1: 267–270p.
9. Li, C.C., X.D. Lin, Zhou, X. Bao, and J. Huang. Fuzzy control of electro-hydraulic servo systems based on automatic code generation. Proceeding of the 6th International Conference on Intelligent Systems Design and Applications, Oct.16-18, IEEE Computer Society, Washington DC, USA, 2006, pp. 244-247.
10. Kwanchai Sinthipsomboon. Industrial Hydraulic, Re-education public company limited, 1987, pp. 25-87.
11. Darrel Janesak and Dave Roepp. Hybrids make a move to the plant floor, Hydraulics & pneumatics, August 2006, pp. 32-49.
12. Ramesh. S, S. Denis Ashok, Shanmukha Nagaraj, et.al., (2018). Energy conservation strategy in Hydraulic Power Packs using Variable Frequency Drive. IConAMMA-2017. IOP Conf. Series: Materials Science and Engineering 310 (2018) 012041 doi:10.1088/1757-899X/310/1/012041
13. Ramesh S, S Denis Ashok, Shanmukha Nagaraj, (2018). An Energy Conservation Strategy Using Variable Frequency Drive for a Hydraulic Clamping System in a CNC Machine. Materials Today: Proceedings, Elsevier Science Direct publisher, ICMMM – 2017, Volume 5, Issue 5, Part 2, 2018 Pages13504-13513. doi: 10.1061/j.matpr.2018.02.346.
14. Kittiphong Poomphochana, Pornjit Pratumsuwan et. al., (2013)." Energy saving in Electro-Hydraulic System using Impedance Sensing". 3rd International Conference on Electric and Electronics (EEIC 2103), Published by Atlantis Press, PP245-248.
15. Lv C, Wang H, and Cao D. (2017). "High-precision hydraulic pressure control based on linear pressure-drop modulation in valve critical equilibrium state". IEEE Transactions on Industrial Electronics, 64(10), 7984-7993.
16. Ramesh S., S. Denis Ashok, Shanmukha Nagaraj, Thangadurai N (2018) "Energy Conservation Approach and Control Strategy for Open Loop, Closed Loop Hydraulic Circuit in CNC Machines" International Review of Mechanical Engineering (I.RE.M.E.), Vol. 12, N. 11 ISSN 1970 - 8734 November 2018. https://doi.org/10.15866/ireme.v12i11.16159.

AUTHORS PROFILE

Ramesh.S, acquired his M.Tech., in CAD/CAM also, Pursuing Ph.D.from VIT University, Vellore. Currently he is employed at Jain Deemed to be University, as Assistant Professor in the Department of Mechanical Engineering. With his experience in teaching and research he has published a number of papers in various international and national journals. He has written a book titled "A textbook of Rapid Prototyping", published and distributed by Ane Books Pvt. Ltd. He is perceived as a reviewer for McGraw-Hill Education (India) Pvt. Ltd. and reviewer for ahigh indexed international journal. His areas of interest include Fluid Power System, 3-D/4-D Printing, Computer aided Design and Manufacturing, Industrial Automation.

Dr. Denis Ashok has acquired his Ph.D. in Mechanical Engineering from IIT Madras, Masters of Engineering from Madurai, Thiagarajar College of Engineering. Currently he is employed as a Professor in the Department of Design and Automation, School of Mechanical Engineering, VIT, Vellore. He has Published more than 50 research articles papers in International Journals of high repute. He has completed Projects supported by Central Poultry Development Organization, Chandigarh, The Tata Power Company, Mumbai, DST and so on. He has Received the "Innovation and Leadership grant - 2013", for the commitment of improvement of first indigenous advancement of egg vending machine. His territories of interest are Mechatronics and control systems, Soft Computing and Advanced Signal Processing Techniques, Machine vision and metrology.

Dr. Shanmukha Nagaraj, currently employed at R V College of Engineering, Bengaluru as Professor and Dean Students welfare. He has 12 years of research experience and 23 years of teaching experience. Dr. Shanmukha Nagaraj has received his Ph.D. from Mangalore University. He has published a number of papers in various journals of high repute. Also, he has completed funded Projects by NRB, DST and soon. His research areas of Interest are Fluid Power systems, Composite Materials, Machine Design