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Design and Controlling of Retrofitted 4 Axes Milling Machine for Industrial Applications

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Abstract:**- This paper describes how retrofitting machines are designed and implemented to overcome the requirement of the trained persons to do machine operation manually, these old outdated machines are retrofitted by inserting the proper control technology by using power electronics, electrical and programming software and present new programming technologies.. In the design, axes movements are driven by the servo motors to get a constant toque and spindle speed is driven from the spindle motors with gear system to get a variant speed and torque modes. Because of using motors and the machine control device working depending on the job's requirement we can increase the number axes. Different sensors are used to trace out the movement of the axes and controlling of the axes movements. These sensors will send the signals to the controlling unit in order to stop or start the axes movements. Machine movements were controlling by the programmable logic controllers and the computer numerical control. PLC will support for conditional and sequential operations of the machine. Whereas CNC with help of the part programming and controlling structures the machine can do required operations.**

***Keywords**:-* *Computer numerical control (CNC), PLC, retrofitting, Servo drive, Servo motor. Power Supply Module (PSM).*

I. INTRODUCTION

In early day's machine operated by well trained persons so machine movements were very limited and workspace is very less and the no of axes to work is one only. Complicated parts production is very difficult and impossible to do the batch production. The dimensions of each produced products need to check with respect to size and shape. So, production cost and time will be higher. So this older machines were need to be retrofitted by using electrical, electronics and computer software and programming technologies [1].

Computer numerical machines (CNC) which are used in

Companies are old, outdated and which is worked in aboard environment. These CNC machines were reliable it can be operate up to ten to fifteen years after that we can service CNC for proper operations. Some of the models will lost their reliability so, in that conditions companies were looking in to buy a new machine or to upgrade the old machine to the current technology, this process is so called as "retrofitting". For Small and medium scale industries buying a new machine is very difficult because of the initial investment of the new machine, it is additional financial load to those enterprises. So, these CNC machines were retrofitting using current technology and the suitable control loops. Comparatively retrofitting is cheaper than the buying a new machine. In a present world these kind of situation will rise who brought the old machines. To retrofitting those machines industrial standard motion controls are required, such as drives, PLC etc. these are interfaced with the computers and synchronized the machine work using those computers. This paper describes a retrofitting of CNC machines using drives and PLC.

A closed-architecture Computerized Numerical Control (CNC) system based on Windows operating systems is discussed in the following paper. Here the process is a mainly controlling using the drive system. Here the Drives are controlling using the sine wave PWM control with transistor (IGBT) bridges. The controlling of drives by multi-task embedded system it will compare the required and actual data and gives error signal to the controlling system to gives required the gating signals to the power electronics devices (IGBT). CNC controlling through the windows operating systems, which controls weak real-time tasks like NC code's editor, simulator function block, translator, fault identification and rectification and, input output monitoring and control etc.

The working structure consists of four control layers: interaction layer, control layer, device layer and physical layer. The operator is giving signals to the CNC by inserting the controlling parameters, in the integration control layer; the input NC program is converted into machine instructions. The machine instructions were executed by the motion control layer, which consists of an interpolator and a discrete event control module. The interpolator generates position commands according to the desired motion instructions and speed profile. Other instructions, such as tool selection and coolant control, are handled by the discrete event control module [1]. The device control layer operates the physical devices to realize the machining process. It incorporates an axis control module and a discrete input/output control module. In the study of this paper, the device control layer is implemented by using FANUC packages.

For a CNC milling machine, the motion control are divided into two different parts: the axes motion and the milling motion. The axes motion is controlling the 4 different axis movements by servomotors. While the milling motion is used in the milling process by means of rotating the milling cutter with required speed and torque[2]. The Axes motion is controlling by the servo drives and milling motion is controlling by the spindle drives, these two drives power is supplied by the power supply module.

II. MILLING OPERATION

Milling is the machining process of using rotary cutters to remove material from a work-piece by advancing the cutter into the work-piece at a certain direction. The cutter may also be held at an angle relative to the axis of the tool. Milling covers a wide variety of different operations and machines, on scales from small individual parts to large, heavy-duty gang milling operations. It is one of the most commonly used processes for machining custom parts to precise tolerances. Typical milling operations are:

Plain milling is the milling of a flat surface with the axis of the cutter parallel to the machining surface.

End Milling is the milling of a flat surface with the axis of the cutter perpendicular to the machining surface

Gang milling is a horizontal milling operation that utilizes three or more milling cutters grouped together for the milling of a complex surface in one pass

Straddle milling a group of spacers is mounted in between two side and face milling cutters on the spindle arbor.

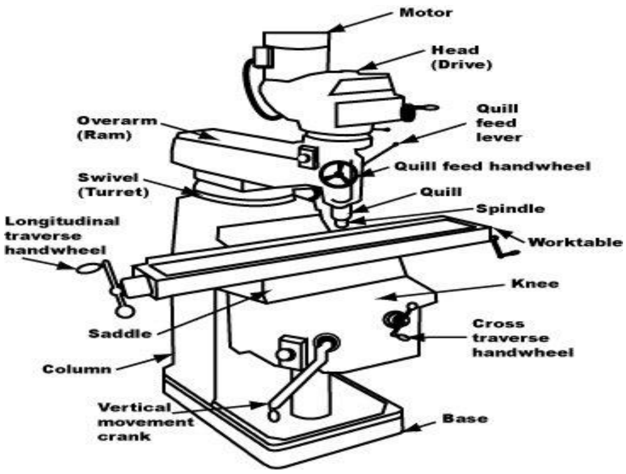

Fig 1:- Typical milling machine

III. WORKING PRINCIPAL

The objectives of the design are i) obtain a complete automated cutting machine. ii) Design the control panel considering all the possible constraints. iii) Achieve sequential flow of operations. iv) User friendly and cost effective.

From block diagram it is explained as, three phase supply is given transformers for the required voltage level then it is given to MCB's, contactors and AC line filter for protection, then it is given to power supply module. PSM is connected in series with spindle and servo drive for power maintenance.

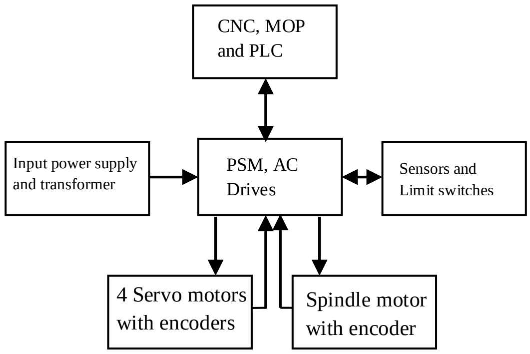

Fig 2:- Block diagram of working principal

Motors are connected to drives for the controlling; feedback is taken from motor to drive for its actual speed and position, depending upon the inputs given to CNC, Motor speed and position will control according to the inputs given and actual measurements. Along with this sensors and limit switches signals will also control the machine movements.

Major components required for automation are Programmable logic controller, Servo Motor Drive, Proximity sensors, solenoids, Computer Numeric Control, and Limit switches. Four servomotors are connected to the Servo drives for the axis movements i.e. X, Y, Z and B axis. One spindle motor is connected to the spindle drive for the milling cutter rotation. Power Supply Module (PSM) is required to proper maintaining the power to the servo and spindle drives. PSM is connected in series with the spindle drive and servo drives. Working of Drives and motors is based on the signal obtained from PLC. The inputs to PLC are signals from sensors. Push buttons are for start and stop operation. CNC is for the communication of the machine with outside world. CNC has LED screen which helps to display the ongoing operation and to even give input for different operations. The sequence to run the machine is done in two ways. In first sequence all the movements take place one after the other in an order second method is based on the choice given by the operator. One or more movements take place according to the choice of operator which can also be called as conditional flow of movements.

IV. CONTROL METHODOLOGY

The milling machine controlling is done by using the CNC part programming starts from analysis of the applications, distance has to move from initial homing position to final end point. Along with that depth of cutting, speed of the spindle (milling cutter) and type of the milling head. Final point of control is by checking the completed job. Below is the controlling methodology of the whole system. The following are the steps of controlling process.

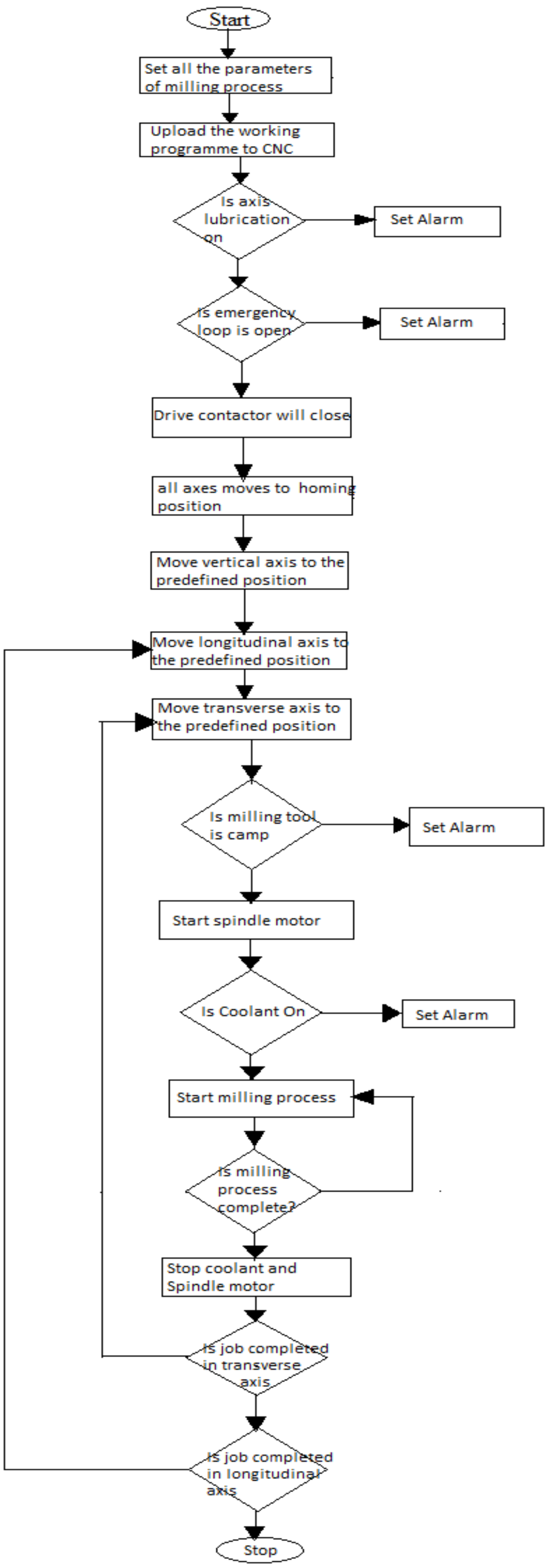

Fig 3:- Flowchart of Proposed Control methodology

V. CONTROL PANEL DESIGN

Control panel is designed for the milling process mainly consists of Programmable Logic Controller (PLC), Servo drives (SD), Spindle drive, Power Supply Module (PSM) Computer Numerical Control (CNC), relay boards, SMPS, MCB's, Contactors and MPCB's etc. These components are assembled and wired and are further connected to the Milling machine. A brief block diagram showing the connection between the control Panel and milling machine is shown in figure 3.

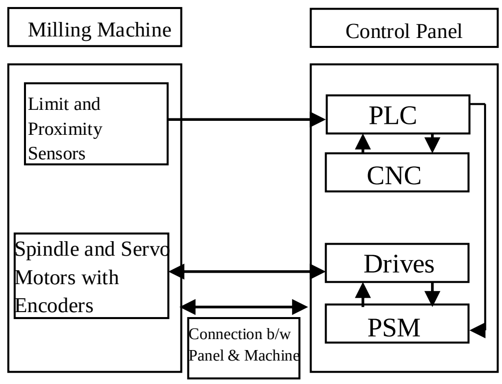

Fig 4:- Block diagram for connections

The block diagram shown is gives an idea about the wiring connections between the milling machine and the control panel that is to be designed. The proximity sensors and limit switches are inputs to PLC. The position of different movements whether at home position or at end position is given to PLC through these sensors. As per the programming done, actuating output signals are given to Drive fed to servo motors and Spindle motors, which results in the movement of the axis in the direction given by the operator. Here the drives are operating on constant v/f ratio. So here Power Supply Module (PSM) controlling the power given to the drives intern controls the speed of the motors. i.e., on actuation of axis drives. Here X axis is for movement of longitudinal direction, Y axis for movement of vertical direction, Z axis for movement of transverse direction. B axis for the rotation of the work-piece on the work table and Spindle drive for controlling the speed of the milling cutter according to the depth of the cutting. The interfacing between the PLC and CNC makes it easy to operate the machine in required directions manually or in auto mode. The components that are included in the control panel and their description are given in the next section.

A. Design Calculations

For the designing of the control panel it is first we have to design the rating of the Servo motors and the Spindle motor[7]. For the rating of Servo motor first we have to calculate the torque acting on the motor shaft, moment of inertia and speed of the motor. For the Spindle Motor is selected according to the power rating and speed. Below we are going to calculate the servo motors rating and spindle motor rating.

Calculations for Cutting forces
D=Diameter of the cutting job-750 mm
n=Min speed of the spindle required = 20 rpm
N=Power of spindle motor= 22 k
P_z=Required Tangential compounent of cutting force
P_X= Required Axial compounent of cutting force
P_y= Required Radial compounent of cutting force

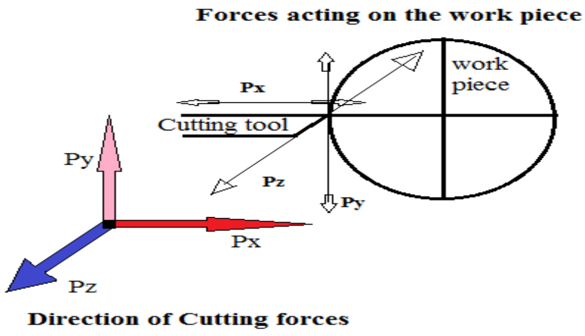

Fig 5:- Cutting Forces on working piece

Tangential compounent of cutting force is calculated as:

P_z=6120*N / v kgf (1)

v=peripheral speed of cutting force m/min

v=(π*D*n) / 1000 (2)

v=(π*750*22) / 1000

v= 47.12 m/min

P_z=(6120*22) / 47.12 = 2857.385 kgf

P_x =0.55 P_z = 0.55* 2857.385 = 1571.56 kgf

P_y= 0.625 P_z = 0.625*2857.385 = 1785.86 kgf

From the above cutting forces value, machine weight, cutting length and required cutting speed servo motor and spindle motor is selected[7]. Here we are selected motor package is from FANUC company[8].

FANUC Components	Specifications
Power supply module for drives	26 kw Rated output
Spindle control Drive	22 kw, 100 A
Spindle motor	22 kw, 12000 rpm
Servo Drive	Rated 22.5 A each axis
Servo motors for	
X axis	22 Nm, 2000 rpm
Y axis	30Nm, 1500 rpm
Z axis	40 Nm, 2000 rpm
Rotary axis(B axis) :	
Servo drive	Rated 6.8 A output
Servo motor	8 Nm, 2000 rpm

Table 1. Selected Funuc package

In the hardware part, component such as SMPS, MCB, Motors, Drive & Switchgear circuit will be integrated to form the complete machine .The hardware components are the backbone of the system. More detailed information of the hardware specifications are;

Component Descripton	Specification	Qty
MCCB-1 with Rot.Handle	3 Pole, 160 Amps	01
MCCB-2 Servo drive	3 Pole, 120 Amps	01
MCB-1 Contactor Supply	2 Pole, 2 Amps	01
MCB-2 SMPS-1	2 Pole, 6 Amps	01
MCB-3 SMPS-2	2 Pole, 6 Amps	01
MCB-4 SMPS-3	2 Pole, 6 Amps	01
MCB-5 Panel AC	2 Pole, 6 Amps	01
MCB-6 Trf-01 O/P	2 Pole, 16 Amps	01
MPCB-1Hydraulic Mtr	1-1.6 Amps	01
MPCB-2 Clamp motor	1.6 – 2.4 Amps	01
MPCB-3 Coolant Mtr	0.4-0.6 Amps	01
MPCB-4 Axis lub Mtr-1	1-1.6 Amps	01
MPCB-5 Axis lub Mtr-2	0.4 - 0.6 Amps	01
MPCB-6 Spindle Fan mtr	0.4 - 0.6 Amps	01
Contactor K1M to K2M	9A, 230 V AC coil	06
Contactor K1A	10A, 230 V AC coil	01
Contactor K2A	10A, 24 V DC Coil	01
Contactor K10M	140A, 230 V AC Coil	01
Contactor K2M	32A, 230 V AC Coil	01
Contactor K7M	140A, 230 V AC Coil	01
SMPS-1,2 & 3	24 V DC, 10 A o/p	03
RELAY 1C/O, 8 CH	24 V DC input	04
Hydraulic motor	0.55 kW, 1420 rpm	01
Coolant motor	0.155kW, 1410 rpm	01
Axis Lubrication motor 1	0.37kW, 1440 rpm	01
Axis Lubrication motor 2	0.075 kW,1440 rpm	01

Table 2. Component list and Specifications

The Figure 4.13.1 below shows the Flow chart of Power supply in control panel

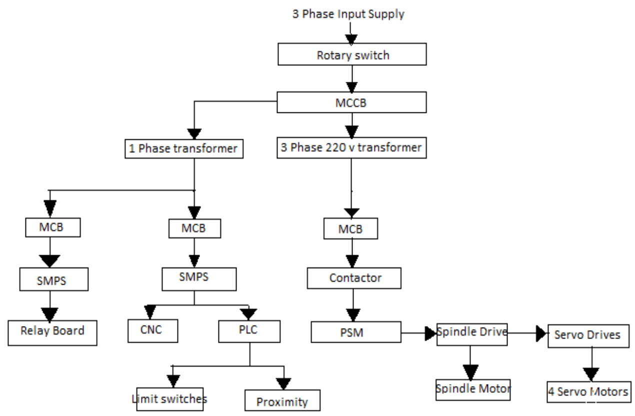

Fig 6:- Flow chart of Power supply in control panel

The input supply to the control panel is 3ph 440V, this supply voltage is given to the transformer through rotary switch and MCCB for protection purpose. The transformer used here is of 3ph 440/220V step down transformer. The output of transformer is given to the MCB then Contactors for safety purpose and then it is given to power supply module, then drives. In another supply line 2 phase 415 volts is given to transformer to convert 1 phase 215 volts. This output is given to various devices used in the control panel and field devices through MCB's. The servo drive and servo motor is operates on 3ph 220v input supply. The 24V dc supply to PLC, HMI, solenoids valves is obtained from the SMPS. The command signal is given from PLC to servo drive and then to the servo motor in order to obtain the desired operation.

The control panel Design consists of two parts: Drive Control panel and CNC control panel. Control panel includes programmable logic controller (PLC), Servo Drive (SD), relay logic board, Switch Mode Power Supply (SMPS), Transformer and Pushbutton switches. Figure 4.11.2 shows the layout of internal arrangement of control panel. The components are mounted on the base plate using din-rail. This arrangement includes PLC, SD, SMPS, relay board, MCB's, contactors, transformer and terminal blocks. Drive control panel power distribution line diagram shown in Figure 5.

This CNC control panel consists of CNC and MOP along with the accessories. This CNC used as the input Device and also the results are displayed in the same screen. Figure 4.13.3 shows the layout of HMI control panel. It consists of HMI display, push buttons and emergency push button, MOP, Keyboard and Joystick.

The panel cut-out is done according the layout diagram and the components are assembled in the panel. Wiring is done as per the power distribution diagram and the Drive output is connected to the Motor via a field wiring. Figure 6 shows the Control Drive panel with accessories.

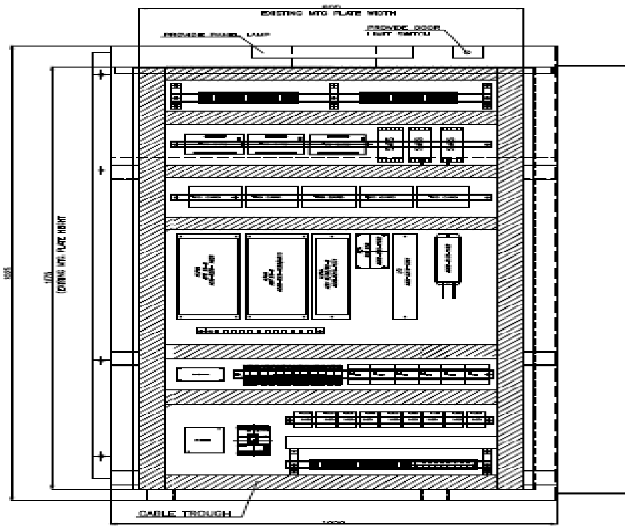

Fig 7:- Layout of internal arrangement of control panel

VI. SOFTWARE REQUIREMENT

The project milling machine control panel design wiring is done by the AUTOCAD 2007 Software. The Programming logic is in done using Fanuc software FANUC PLC v7.6. Fanuc is program-editing software made for the Fanuc DVP-PLC series used under WINDOWS. Along with the general program planning and other general functions. For the Controlling FANUC Computer Numerical Control (CNC) model FS 0i Mate-MD is used to be a means of operating Milling machine through the use of discrete numerical values fed into the machine, The machine follows a predetermined sequence of machining operations at the predetermined speeds necessary to produce a work piece of the right shape and size and thus according to completely predictable results.

VII. RESULTS AND ANALYSIS

The final objective of the project was to design, develop and implement retrofitted milling machine in order to increase the productivity, accuracy, to reduce manpower and to upgrade the technology. The final objective of the project was to design, develop and implement retrofitted milling machine in order to increase the productivity, accuracy, to reduce manpower and to upgrade the technology. As per the design wiring diagram and controlling methodology explained earlier the figure 7 shows the Butler milling machine Control Panel with component Assembly is shown.

Fig 8:- Control Panel components Assembly

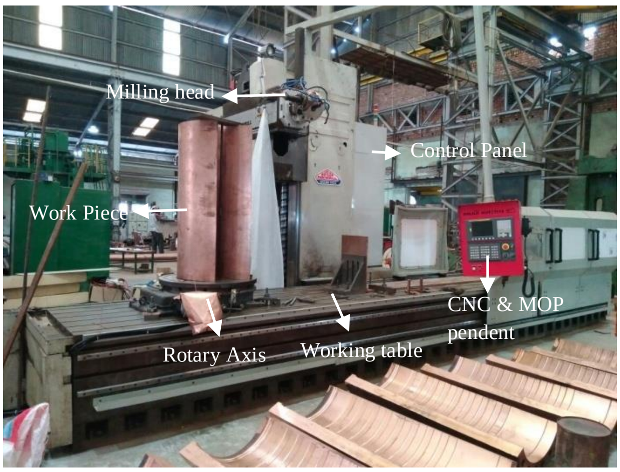

Fig 9:- complete Setup of Butler milling machine.

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The old Milling machine was completely mechanically reconditioned and newly designed control panel, machine wiring and MOP assembled to machine is as shown in the above fig. 8. The machine is commissioned and tested. It is working satisfactory as per requirement given from company. As explained in earlier chapters, the milling machine is controlled with the help of PLC to do the various milling and turning operations with help of various milling tools. In this machine along with the conventional 3 axes Rotary axis is provided to do the specific milling operations is shown in above fig. Whole machine operations are controlling using the CNC system, the axes movements, directions, speed and cutting speed of spindle are controlling as per the CNC part programming for particular applications.

VIII. CONCLUSION

The project mainly deals with the control panel being developed and automation being done using PLC. Control panel is designed considering all the possible constrains, sequential and conditional flow of movements of the milling System achieved by construction of ladder diagram in PLC, PLC and CNC interfaced with each other to achieve effortless communication with the milling machine.

Milling machine has a movement in all three directions as longitudinal, vertical and transverse along with this Rotary axis on the tool bed and Spindle control, for checking the proper functioning of all the mentioned movements a developed system is automated considering all the movements of the milling machine. For ease and sequential functioning of the machine a control panel is developed which includes drives, PLC and CNC. The testing of the whole machine is done successfully in the working conditions considering all the possible constrains with the help of CNC.

IX. ACKNOWLEDGMENT

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