Experimental analytical design of CNC machine tool SCFC based on electro-pneumatic system simulation

Oladapo, Bankole I.; Balogun, V. A.; Oyegoke, S.; Adeoye, A. O.M.; Ijagbemi, C. O.; Afolabi, S. O.

Published in:
Engineering Science and Technology, an International Journal

DOI:
10.1016/j.jestch.2016.08.010

Publication date:
2016

Citation for published version (APA):
Oladapo, B. I., Balogun, V. A., Oyegoke, S., Adeoye, A. O. M., Ijagbemi, C. O., Afolabi, S. O., Daniyan, I. A., Akinola, S. O., Simeon, A. P., & Uchegbu, I. D. (2016). Experimental analytical design of CNC machine tool SCFC based on electro-pneumatic system simulation. *Engineering Science and Technology, an International Journal*, *19*(4), 1958-1965. https://doi.org/10.1016/j.jestch.2016.08.010

Engineering Science and Technology, an International Journal 19 (2016) 1958–1965

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Engineering Science and Technology,
an International Journal

journal homepage: www.elsevier.com/locate/jestch

Full Length Article

Experimental analytical design of CNC machine tool SCFC based on electro-pneumatic system simulation

Bankole I. Oladapo [a,*], V.A. Balogun [a], S. Oyegoke [b], A.O.M. Adeoye [a], C.O. Ijagbemi [c], S.O. Afolabi [a], I.A. Daniyan [a], S.O. Akinola [d], A.P. Simeon [a], I.D. Uchegbu [a]

[a] Mechanical and Mechatronics Engineering, Afe Babalola University, Ado-Ekiti, Nigeria
[b] Civil Engineering, Afe Babalola University, Ado-Ekiti, Nigeria
[c] Mechanical Engineering, Federal University of Technology, Akure, Nigeria
[d] Electrical and Computer Engineering, Afe Babalola University, Ado-Ekiti, Nigeria

ARTICLE INFO

Article history:
Received 11 May 2016
Revised 6 July 2016
Accepted 14 August 2016
Available online 12 September 2016

Keywords:
Simulation
Work-piece
Magnetic proximity switch
CNC machining
Clamping force
Manufacturing

ABSTRACT

A Smart Clamping Force Control (SCFC) is adapted to hold sensitive workpiece using magnetic proximity switch during a machining operation on the CNC machine tool. It has been ascertained that work-holding of different workpiece materials and shapes during machining operation is one of the problems encountered during CNC milling machining operations. This work proposes a novel clamping strategy for workpieces with the aid of SCFC. The purpose of the study is to adjust the forward movement of the clamp and reduce the damage caused by the clamp on the workpiece, this depends on the material of the workpiece. The speed of the clamp is reduced using the inlet flow control throttle valve and a magnetic proximity switch (MPS). It provides careful handling of workpiece and prevent it from damage and as well optimizes the forward movement of the cylinder. The proposed strategy is based on dynamic machine loading in which the impact of applied forces were monitored to optimize the clamping control system of the machine tool. The mode of operation and performance of the SCFC were simulated in the FluidSIM® software, and the validated results was presented on Festo workstation. This work therefore further elucidate the fundamental design criterion for machine tool clamping forces and the sustainable manufacture of its components.

1. Introduction

In recent times, the Original Equipment Manufacturer (OEM) encountered diverse problems in the design and development of groundbreaking products to meeting highly competing for global market demand [1]. For example, the complexity and ability to produce acceptable surface integrity in machining operations, especially in milling operations were reported by Balogun et al., 2015 and 2016 [2,3]. The adoption of the 5-axis CNC milling machine has become widely used due to its capability to produce a better surface finish and the ability to be used for machining complex geometries [4]. Unfavourable machining system dynamic as a result of different cutting parameters, two-part strategy and workpiece materials could lead to the machine tool vibration. This also would have a negative effect on the production process as a whole [5,6]as a result of excessive cutting tool wear and heat generation within the workpieces.

It has been established that with appropriate planning and analysis of machining and manufacturing process, time, resource can be optimized [7–9]. Time resource management and optimization are important judging by the complexity of the setup time variations in a five-axis CNC machine tool. Also, delamination of the workpiece and tool poses another difficult challenge to the machining engineers. This could lead to various damages as experienced during machining [10–13]. Delamination is the most common type of damage to the workpiece. It could occur at the upper side of the workpiece called ‘peel-up’ delamination and at the lower end of the workpiece called ‘push-out’ delamination [14]. Delaminations are mostly caused by the clamping process or methods of the work holding devices of the workpiece. In order to avoid the damage caused by this clamping process during the machining

---

[*] Corresponding author.

E-mail addresses: bankolyable@yahoo.com (B.I. Oladapo), balogunav@abuad.edu.ng (V.A. Balogun), soyegoke@gmail.com (S. Oyegoke), aadeoye@abuad.edu.ng (A.O.M. Adeoye), tadeijagbemi@gmail.com (C.O. Ijagbemi), afowolesam@yahoo.com (S.O. Afolabi), afolabiilesanmi@yahoo.com (I.A. Daniyan), soakinola@abuad.edu.ng (S.O. Akinola), engnrsimeon4real@yahoo.com (A.P. Simeon), Uchegbus17@gmail.com (I.D. Uchegbu).

Peer review under responsibility of Karabuk University.

http://dx.doi.org/10.1016/j.jestch.2016.08.010
2215-0986/© 2016 Karabuk University. Publishing services by Elsevier B.V.

operation, the geometry and the material of the workpiece has to be put into consideration. Furthermore, complex-clamping systems are required for the material of complex geometry during the mechanical machining processes to ensure machining precision of the tools on the workpiece [15,16]. Few researchers [16,17] also shows that the quality of the workpiece produced depend extensively on the process parameter, workpiece material, clamping force, positioning and system of clamping points.

Electro-pneumatic control systems play very significant roles in industrial automation systems because of the advantages of easy maintenance, cleanliness, low cost of production, availability and low energy consumption [18–20]. Particularly this system uses 24 V power supply as an energy source and operates on a low pressure of 6 bar. This is common for most electro-pneumatic control actuator system of double acting cylinder. Although pneumatic actuators operate on dead-band due to striation, high friction forces and dead-time due to the compressed air, they are being minimized due to the introduction of the electro-pneumatic system incorporated into the system to aid compatibility, good functionality, and easy operation. Fig. 1 shows a section view of a typical electro-pneumatic assembly of the clamping system for a CNC milling machine.

From literature and due to the problems encountered (i.e. delamination), it is pertinent to investigate and analyze the clamping systems during machining operations especially when clamping highly sensitive materials. Given this, the aim of this novel research is to model and simulate an Smart Clamping Force Control *SCFC* system, which is adapted for clamping within the manufacturing industry, with a capability of sensing the ‘ON’ and ‘OFF’ clamping systems for workpieces during mechanical machining operations.

1.1. Aim and objectives

In the commercially available industrial CNC machine tools adopted for the production of various machine parts and components, process methods are pursued in variance to machine efficiency and sustainable manufacture. In view of this, consumers’ products are monitored manually from stage to stage through individual observations for quality and conformity. The machine is stopped if there is any form of damage or an alarm system is triggered in the event of nonconformity [21]. This is possible since the operating conditions are being monitored during processing by different methods within the machining system. Therefore, there is a higher risk of tool fracture, which can be reduced or totally eliminated by having good and workable clamping system (i.e. electro-pneumatic control). The aim of this research is to propose a novel design model for the SCFC system of CNC machine tool clamping system. To achieve this clamping strategy, the *SCFC* system is simulated to understudy the working principles with the aid of the FluidSIM software and the result compared with available literature.

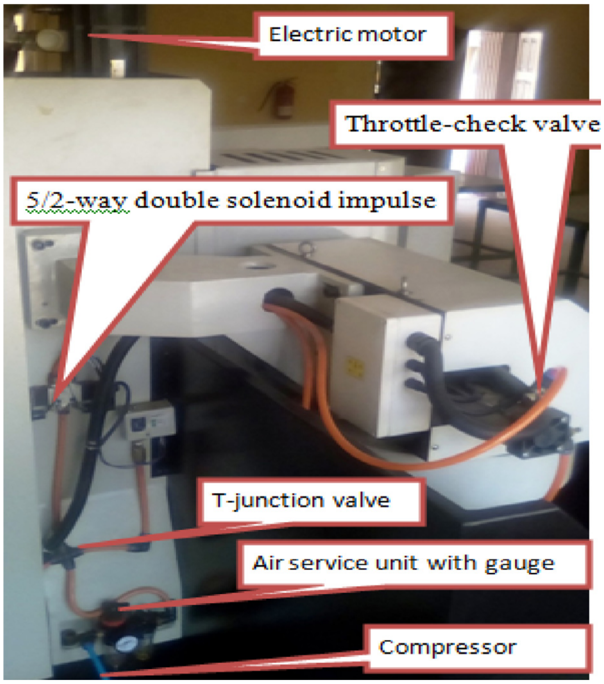


Fig. 1. Electro-pneumatic assembly of the CNC milling machine.

2. Experiments

2.1. Experimental scope

To investigate different clamping method of workpieces on the CNC machine tool, different camping systems were simulated. A clamping system with pneumatic controls is designed. Furthermore, an electro-pneumatic collection operating with a push button for both the forward and backward clamping was initially adopted. The clamping sensor helps to detect the material of the workpiece and allows it to move at a slow speed for the forward stroke. This is to allow clamping without damaging the work piece. The commercially available system in CNC milling is as show in Fig. 2.

In an idea clamping operation, (where the workpiece is fixed at the position for the machine by another double acting cylinder) the *SCFC (*Smart Clamping Force Control) clamp system ensures that the degrees of freedom are restructured and no deflection occurs.

2.2. The SCFC experimental and simulation apparatus

A schematic circuit diagram of the SCFC system adopted for simulation is as shown in Fig. 3. The tools adopted for the experimental and simulation are as stated in Table 1. An 8 GB RAM, Core i5-compatible Laptop computer with 2.4 GHz speed processor, was used to model the control and simulate the setup. The stroke arm of the double acting cylinder (designated DSNU-20-100-PPV-A) for clamping is 100 mm while its working diameter is 20 mm with an internal surface area of 314.16 mm^2. The working piston diameter and ring area of the double acting cylinder are 8 mm and 263.89 mm^2 respectively. A linear scale of length 200 mm was used to measure the experimental linear displacement of the double acting cylinder. The maximum pressure in the system is 10 bars while the working pressure is 6 bar, measured with a pressure gauge (see Fig. 4).

Where,

1A1 represent pneumatic double acting cylinders with a magnetic cushion that serves as internal braking systems and allows smooth clamping with the screw adjuster to control the magnetic cushion.

1B1, 1B2 – (D: TP-BG-PZVT-3/2G-3OS-Q4), This is the symbolic representation of the two magnetic proximity switch. A meter rule for distance measurement of a total length of 200 mm long, 1V2 represents one-way flow control valve which is a combination of the throttle valve and a check valve, that slow down the forward movement of the clamping system. It has a throttle and check valve standard nominal flow rate of 45 L/min and 65 L/min respectively;

1V1-5/2-way double solenoid impulse valve structure (VUVG-L10-B52-T-M5-1P3), with a standard nominal flow rate of

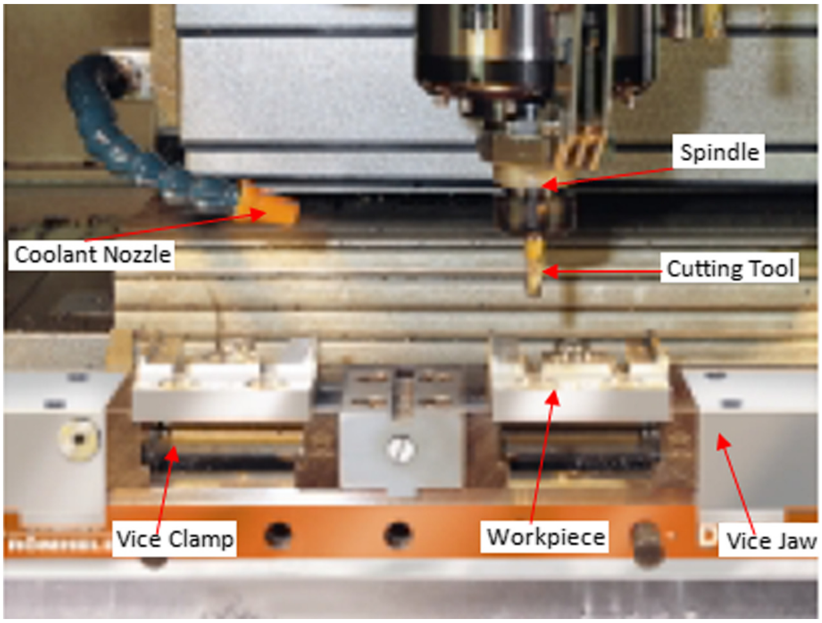


Fig. 2. Flexible double clamping system (*SCFC*): an ideal clamping system.

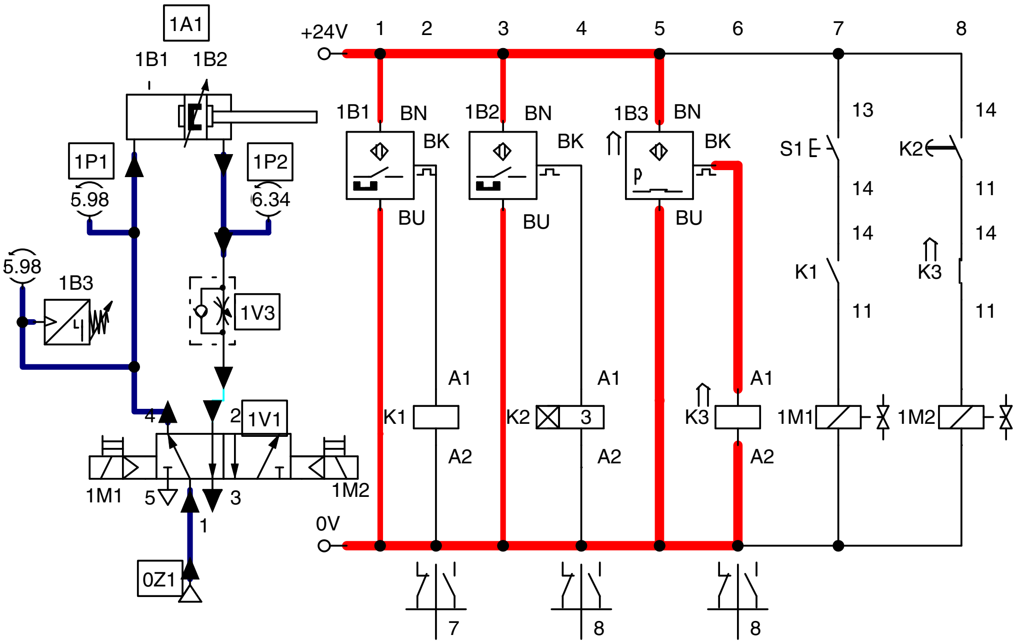


Fig. 3. The schematic diagram of the SCFC system.

1000 L/min that changes the direction of the flow of the air inlet and outlet and also serves as an emergency breaker.

K1, K2, and K3 are relay triggered immediately by their respective limit switch as current is being supplied to the system and switch off immediately when currently is out of the system. 1B3, represent the pressure sensor which was connected with a switch relay of an electrical signal when current passes through the system, and the pressured air is switch ON. It also measures the pressure output and can be regulated from the up and down button as shown in Fig. 5. The digital module was adapted to control the compressed digital switching circuit for the relay switch and the delay timer of the system in the electro-pneumatic circuit. The time can be set depending on the time for machining operation to finish a particular task on the CNC milling machine.

The clamping of the workpiece through electro-pneumatic double acting cylinder was controlled by pressing a push button S1 then the piston rod of the cylinder moves out gently to clamp the workpiece. This energizes the magnetic proximity switch. There is a magnetic bar at the end of the cylinder that serves as a cushion and allows the clamping devices to press the workpiece gently and prevent the workpiece from delamination. The retraction of the clamp is automatic by detecting the magnetic switch at the front of the cylinder after the machining operation is completed based on the specified time.

Table 1
Tool used in experiments and simulation of *SCFC* system with fluidSIM.

Number of items	Description
1	Double acting cylinder
1	Electrical connection 24 V
1	Electrical connection 0 V
1	Distance rule
1	5/2-way double solenoid impulse valve
2	Magnetic proximity switch
2	Relay
1	Pushbutton (make)
3	Make switch
2	Valve solenoid
2	Pressure sensor
1	Manometer
1	One-way flow control valve
1	Relay with switch-on delay
1	Compressed air supply
1	Air service unit, simplified representation
1	2/n way valve

2.3. Characteristics of magnetic proximity switch and time delay valve for SCFC system

It is important to understudy the working principles of the magnetic proximity switch in the electro-pneumatic system. In this system, the sensing and the delay sensor causes the system to return to its initial position with a push or actuation method [15,18]. Two of the magnetic proximity switches were used to aid the forward and the backward stroke of the developed clamping system that mimics the CNC machine tool clamping system. The dead and the rise time of the system were imputed into the on delay timer for the specific time that is needed for the milling task to be completed. The 5/2 double solenoid valve becomes energized when the signal is applied to the system and to the two magnetic proximity switches as shown in Fig. 5.

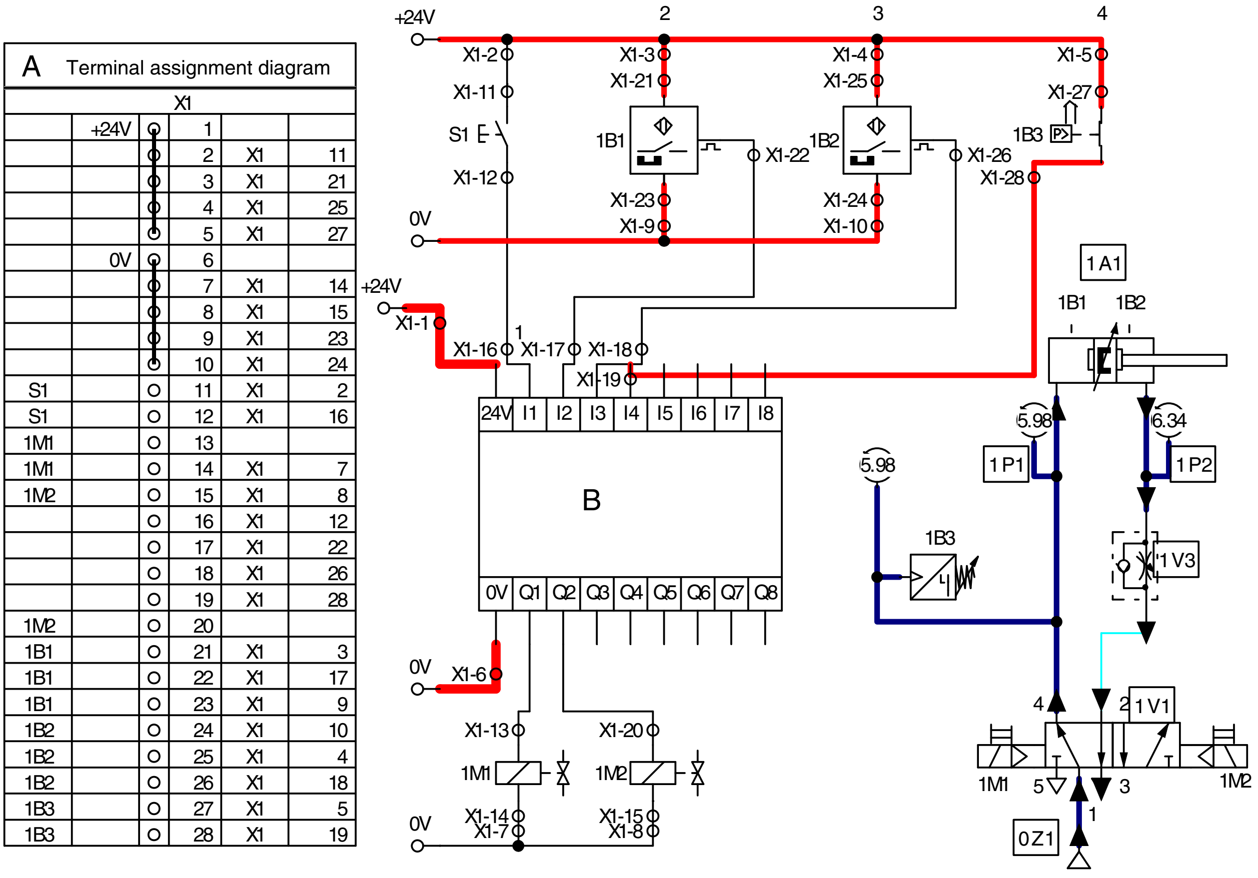
Fig. 1 shows the CNC milling machine. The system in the workstation for experimental setup is shown in Fig. 5. Both Figs. 1 and 5 have the same pneumatic operation set up and almost all components in the CNC milling for clamping operation is also represented in the experimental setup and simulation of the SCFC. The 5/2 way valve of double solenoid impulse, Throttle-check valves, T-junction and air service unit were used in the CNC milling machine. It is also the major controllers in the experimental set-up of the new propose SCFC.

3. Mathematical calculation

The working forces can be calculated by finding the quotient of the grains into smaller unit along the cutting edges of the workpiece and tools. According to Kienzle equation [22], if the total force in the direction of the cutting tool tangential to the grain face is determined according to the cutting edges equation:

$$f = -nkc_{,sim}bd_0\left(\frac{d'}{d_0}\right)1 - mc, sim \qquad (1)$$

where n: is the normal vector of the cutting face, $k_{c,sim}$: is the specific cutting force, $m_{c,sim}$: is the exponent parameter, b: is the width of the cutting edge, d_0: is 1 mm, and d': is the projected grain-immersion depth.



A Terminal assignment diagram					
X1					
	+24V	○	1		
		○	2	X1	11
		○	3	X1	21
		○	4	X1	25
		○	5	X1	27
	0V	○	6		
		○	7	X1	14
		○	8	X1	15
		○	9	X1	23
		○	10	X1	24
S1		○	11	X1	2
S1		○	12	X1	16
1M1		○	13		
1M1		○	14	X1	7
1M2		○	15	X1	8
		○	16	X1	12
		○	17	X1	22
		○	18	X1	26
		○	19	X1	28
1M2		○	20		
1B1		○	21	X1	3
1B1		○	22	X1	17
1B1		○	23	X1	9
1B2		○	24	X1	10
1B2		○	25	X1	4
1B2		○	26	X1	18
1B3		○	27	X1	5
1B3		○	28	X1	19

Fig. 4. (A) Signal control section with programmable logic controller (PLC) of the digital module showing terminals, (B) terminal assignment list for the *SCFC* system.

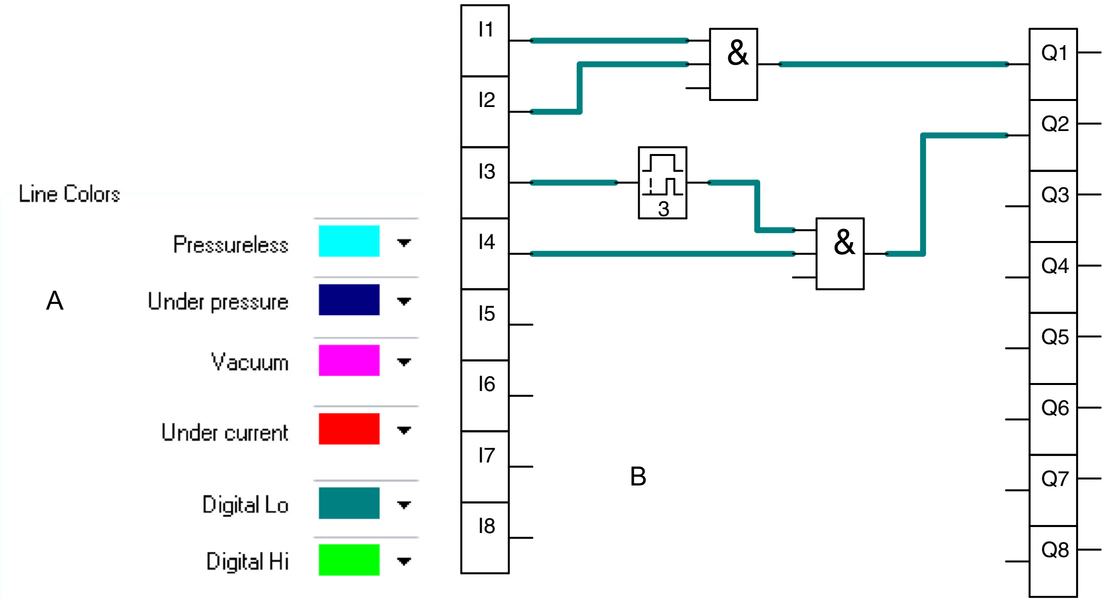


Fig. 5. (A) Legend for the line description of all the circuits. (B) Simulation logic control state of a compacted SCFC system after actuation.

To calculates annularly plane plates deflection *b that occurs during working operation on* work-piece is determine by the equation below [23–26].

$$b = \frac{Fr^2}{16\pi K}\frac{3+\mu}{1+\mu} \tag{2}$$

The stiffness of the plate *K* can also be define as:

$$K = \frac{EK^3}{12(1-\mu^2)} \tag{3}$$

F: is the area force, *E*: Young's modulus, *h*: the thickness, μ: Poisson's ratio.

Ft = *f* (*G*, *M*, F_n, ξ_1). Represent the description of the change of radial F_r and tangential F_t of the cutting force with respect to time is taken in operation [25–28]. Where:

G: Parameters that define the contact
M: Parameters for material properties of the contact;
F_n: Normal interface load for clamping force
ξ_1: Interface compliance.
R: Gas constant
T: Negligible temperature within the system

$$q_1 + q_2 + 2q_3 = c_0\dot{P}_1 + (a_1 + a_2)\dot{x}, \tag{4}$$

where $a_1 = P_1A_1/RTs$; $a_2 = P_2A_2/RTs$; q_i is flow rate through each of the valves; x is controlled piston position; V_1 and V_2 are volumes of the double acting cylinder; P_1 and P_2 are the input and output pressures applied respectively to the system and *Ai* is the cross-sectional area of the double acting cylinder.

$$\frac{dP_1}{dt} = n \cdot \frac{R \cdot T \cdot G_1 - A_1 \cdot P_1 \cdot v}{V_{02} - A_1 \cdot x} \tag{5}$$

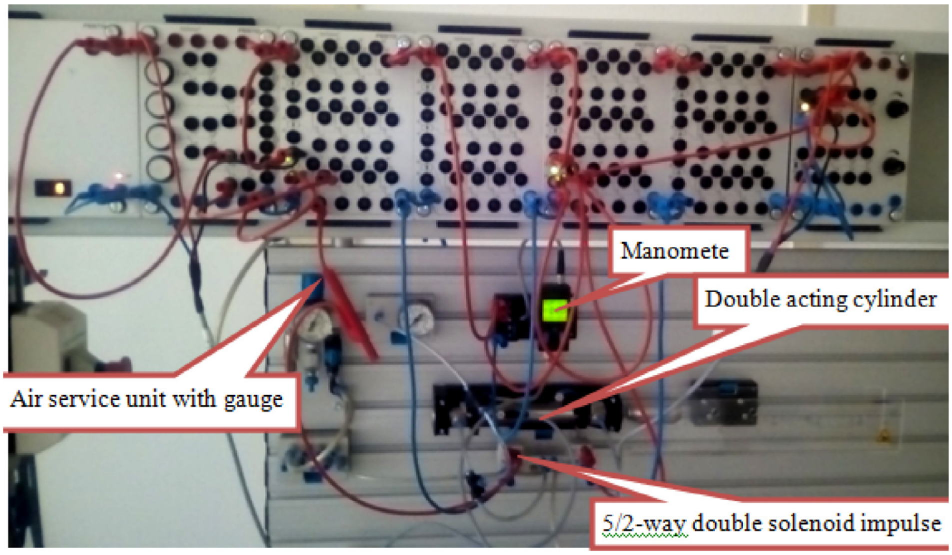


Fig. 6. Experimental apparatus for SCFC system.

$$\frac{dP_2}{dt} = n \cdot \frac{-R \cdot T \cdot G_2 - A_2 \cdot P_2 \cdot v}{V_{02} - A_2 \cdot x} \tag{6}$$

3.1. Developed model equation for SCFC

From Eq. (1) substituting the value of a_1 and a_2, the temperature kept constant We then derive the model equation to be.

$$q_1 + q_2 = c_0 P_i + \left(\frac{P_1 A_1 + P_1 A_2}{R} \right) \dot{x} \tag{7}$$

If all the parameters of the system are taken into consideration. Where $A_1 = 0.00031415\ \text{m}^2$, $A_2 = 0.0002638\ \text{m}^2$, $x = 0.1$ m and R is the specific dry air constant = 287.05 J/kg^{-1} K^{-1} or 0.28705 J/kg^{-1} -K–05 kJ/kg^{-1} K^{-1} The working input pressure is $P_1 = 6.0$ bar and $P_2 = 0.0$ bar from the result in Figs. 6 and 7. Thus when there is an input pressure there is no output pressure and vice-visa. The Equation can finally become:

$$q_1 + q_2 = C_0 P_i + 0.00656 \frac{d}{dt}(x) \tag{8}$$

4. Result and discussion

Figs. 7 and 8 show a graphical representation of the simulation and the experimental result of the signal control section of the Smart electro-pneumatic force control clamping system. The relay in the system is for signal processing of the actuator. As observed from Figs. 7 and 8, the velocity of the double acting cylinder 1A1 move in the positive direction. Also, at the point of actuation, it moves to the negative and then at the point of returning to the cylinder.

The logic circuit board also represents a different control section of the system to compact and reduce hard wiring problems. The 1M1 and 1M2 are the 5/2 double solenoid valves with directional control valves connected to the controller output actuated through the relays in the system.

The magnetic proximity switches 1B1 and 1B2 are connected to the PLC input, and the reaction of the system is as shown in Figs. 7–9.

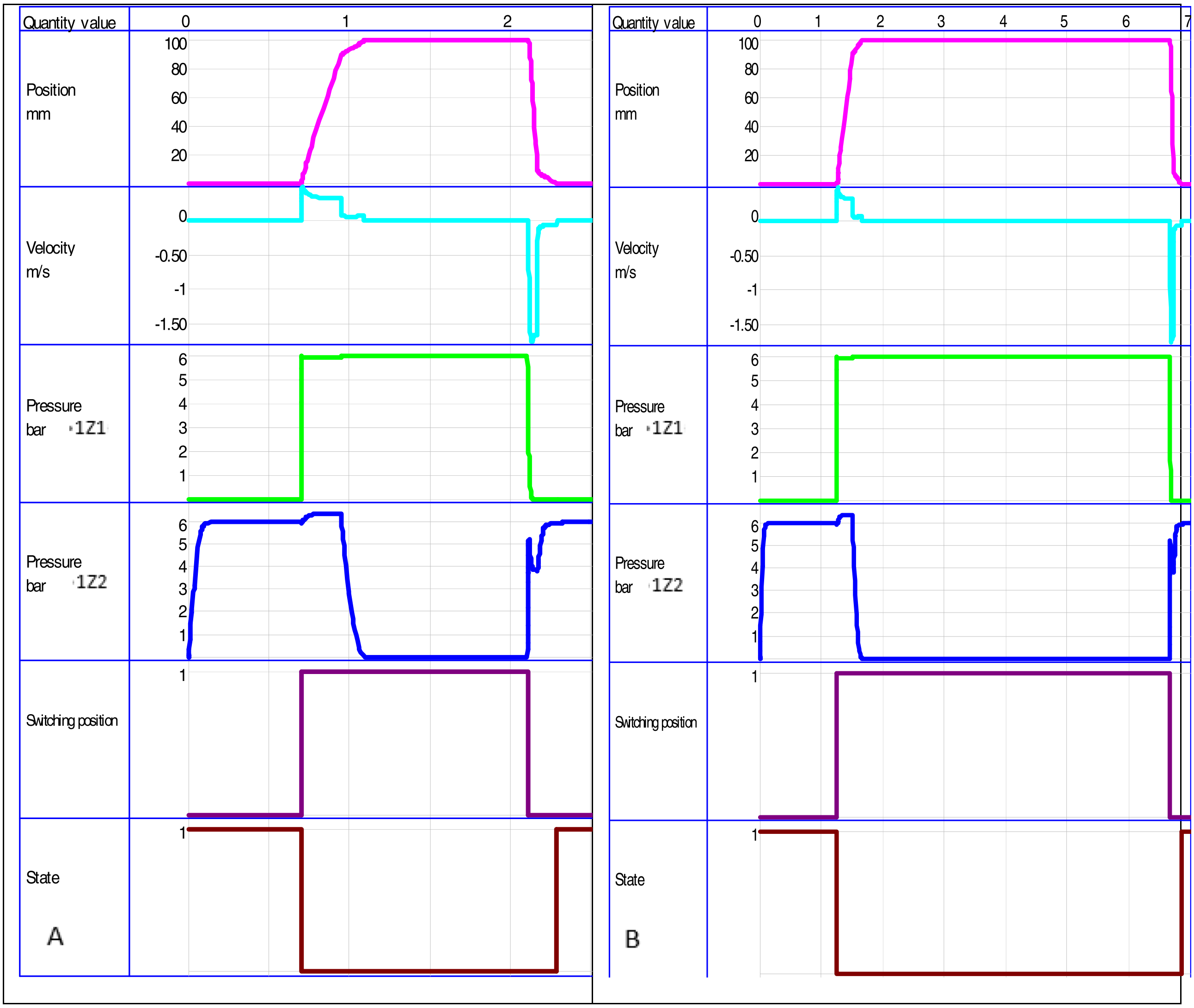


Fig. 7. The pneumatic component, 1B1 magnetic switch and its relay.

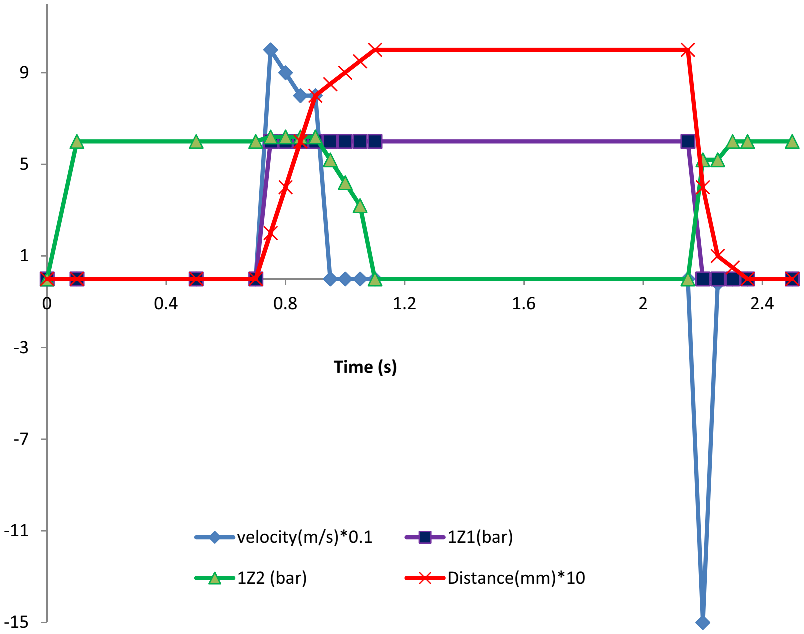


Fig. 8. SCFC system circuit actuation for 1 s.

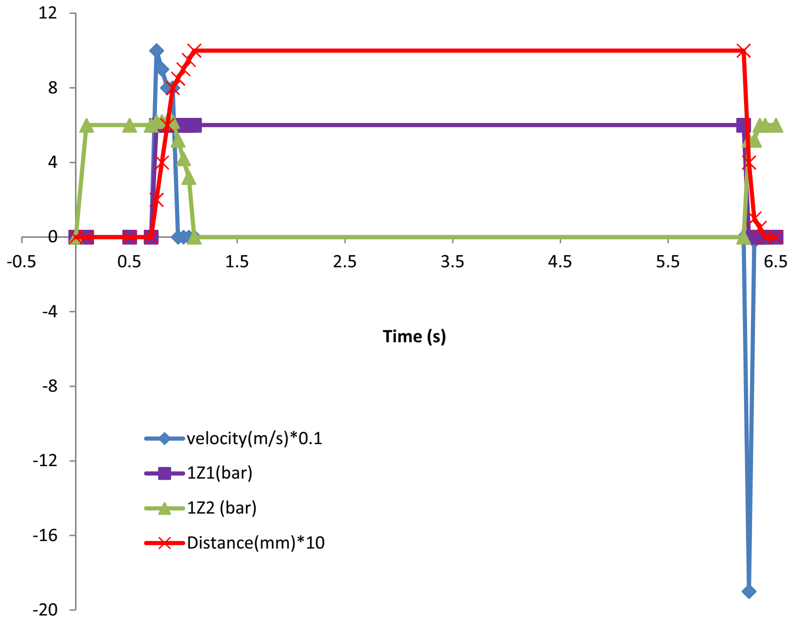


Fig. 9. SCFC system circuit actuation for 5 s.

5. Conclusion

This paper presents the results of the modelling of a smart electro-pneumatic clamping control device for CNC milling in industrial operations. The cost of expensive energy is saved. The electro-pneumatic clamp of 24Vs is fast, accurate of load independent and it is a development of an *SCFC* system with a variable clamping method of force control. The purpose is to adjust the forward movement of the clamp and reduce the damage caused by the clamp on the workpiece depending on the material of the work-piece. The clamping force is controlled by the magnetic cushion in the cylinder. The clamp is timed according to the operational time of the machine and the cutting tool which has a time delay relay attached to it, this is to be set according to the compacted circuit and the wiring circuit. The clamp then automatically opens on its accord by the actuation of the magnetic proximity switch.

References

[1] Felix Damrath, Anton StrahiloV, Thomas Bär, Michael Vielhaber, Experimental validation of a physics-based simulation approach for pneumatic components for production systems in the automotive industry, Proc. CIRP 31 (2015) 35–40.

[2] V.A. Balogun, Isuamfon F. Edem, Paul T. Mativenga, Specific energy based characterisation of tool wear in mechanical machining processes, Int. J. Sci. Eng. Res. 6 (5) (2015) 1674–1680.

[3] Vincent A. Balogun, Isuamfon F. Edem, A.A. Adeleke, P.T. Mativenga, Specific energy based evaluation of machining efficiency, J. Cleaner Prod. 116 (2016) 187–197.

[4] D. Biermann, A. Zabel, T. Brüggemann, A. Barthelmey, A comparison of low cost structure borne sound measurement and acceleration measurement for

detection of workpiece vibrations in 5-axis simultaneous machining, Proc. CIRP 12 (2013) 91–96.

[5] Ahmed Al-Khazraji, Samir Ali Amin, Saad Mahmood Ali, The effect of SiC powder mixing electrical discharge machining on white layer thickness, heat flux and fatigue life of AISI D2 die steel, Eng. Sci. Technol. Int. J. 19 (3) (2016) 1400–1415.

[6] Ravindranadh Bobbili, V. Madhu, A.K. Gogia, Modelling and analysis of material removal rate and surface roughness in wire-cut EDM of armour materials, Eng. Sci. Technol. Int. J. 18 (2015) 664–668.

[7] Mohammad Mi'radj Isnaini, Ryuta Sato, Keiichi Shirase, Workpiece setup simulation based on machinable space of five-axis machining centers, Proc. CIRP 14 (2014) 257–262.

[8] T. Moriwaki, Multi-functional machine tool, CIRP Ann.-Manuf. Technol. 57 (2008) 736–749.

[9] K. Shirase, S. Fujii, Machine tool automation, in: S.Y. Nof (Ed.), Handbook of Automation, Springer, New York, 2009, pp. 837–857.

[10] W. König, C. Wulf, P. Graß, H. Willerscheid, Machining of fibre reinforced plastics, Ann. CIRP 34 (2) (1985) 537–548.

[11] F. Ullmann, Bearbeitbarkeit faserverstärkter Kunststoffe; Frankfurter Kunststoff Symposium, Faserverstärkte Polymerverbund- Werkstoffe im Großserien- und Kleinteilebereich; in: Schriftenreihe Praxis Forum, Fachbroschüre Kunststofftechnik 08(91) (1991) 78–93; Frankfurt a.M., Deutschland.

[12] S. Rummenhöller, Werkstoffangepaßte Bearbeitung von Faserverbund-Kunststoffen, VDI Berichte Nr. 965 (2) (1992) 17–30.

[13] W. König, Grundlagen zur Bearbeitung von Verbundwerkstoffen und Werkstoffverbunden, VDI Berichte Nr. 965 (2) (1992) 1–15.

[14] H. Hocheng, C.K.H. Dharan, Delamination during drilling in composite laminates, J. Eng. Ind. 112 (1990) 236–239.

[15] Bankole I. Oladapo, V.A. Balogun, A.O.M. Adeoye, C.O. Ijagbemi, Afolabi S. Oluwole, I.A. Daniyan, A. Esoso Aghor, Asanta P. Simeon, Model design and simulation of automatic sorting machine using proximity sensor, Eng. Sci. Technol. Int. J. 2 (2016) 2.

[16] Stefan Klotza, Frederik Zangera, Volker Schulze, Influence of clamping systems during milling of carbon fiber reinforced, Compos. Proc. CIRP 24 (2014) 38–43.

[17] S. Klotz, M. Gerstenmeyer, F. Zanger, V. Schulze, Influence of clamping systems during drilling carbon fiber reinforced plastics, in: 2nd CIRP Conference on Surface Integrity (CSI), 28.-30.05.2014 Nottingham, Procedia CIRP, vol. 13, 2014, pp. 208–213.

[18] Berend Denkena, Dominik Dahlmann, Johann Kiesner, Sensor integration for a hydraulic clamping system, Proc. Technol. 15 (2014) 465–473.

[19] B.I. Oladapo, A.V. Balogun, S.O. Afolabi, M.T. Azeez, P.S. Asanta, Simulation model to explore the characteristic pump curve of an injection molding machine: a case study of ABUAD water plant, Int. J. Eng. Bus. Enterprise Appl. 13 (1) (2015) 63–68.

[20] Kyoungkwan Ahn, Shinichi Yokota, Intelligent switching control of pneumatic actuator using on/off solenoid valves, Mechatronics 15 (2005) 683–702.

[21] Mohamed Elhelw, Shimaa Mohamed, Modeling for the influence of variable inlet airflow states on liquid desiccant wheel performance at low flow conditions, Alexandria Eng. J. 54 (2015) 1019–1027.

[22] Mahmoud Gamal, Nayera Sadek, Mohamed R.M. Rizk, Ahmed K. Abou-elSaoud, Delay compensation using Smith predictor for wireless network control system, Alexandria Eng. J. 55 (2) (2016) 1421–1428.

[23] Amitesh Goswami, Jatinder Kumar, Investigation of surface integrity, material removal rate and wire wear ratio for WEDM of Nimonic 80A alloy using GRA and Taguchi method, Eng. Sci. Technol. Int. J. 17 (2014) 173–184.

[24] E. Hake, K. Meskouris, Statik der Flächentragwerke. 2. Aufl., Springer Berlin Heidelberg, 2007. ISBN 978-3-540-72623-4.

[25] Biswajit Das, S. Roy, R.N. Rai, S.C. Saha, Application of grey fuzzy logic for the optimization of CNC milling parameters for Al–4.5%Cu–TiC MMCs with multi-performance characteristics, Eng. Sci. Technol. Int. J. 19 (2016) 857–865.

[26] Abdel.-Hamid. Attia, Sohair.F. Rezeka, Ahmed.M. Saleh, Fuzzy logic control of air-conditioning system in residential buildings, Alexandria Eng. J. 54 (2015) 395–403.

[27] Djordje Vukelic, Branko Tadic, Dragomir Miljanic, Igor Budak, Petar M. Todorovic, Sasa Randjelovic, Branislav M. Jeremic, Novel workpiece clamping method for increased machining performance, Technical Gazette 19 (4) (2012) 837–846.

[28] B. Tadic, D. Vukelic, J. Hodolic, S. Mitrovic, M. Eric, Conservative-force-controlled feed drive system for down milling, Strojniski vestnik – J. Mech. Eng. 57 (5) (2011) 425–439.