Microprocessor stand for DC motor analysis with independent excitation

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Abstract: *In their way of operation, electric motors are in themselves electromechanical systems, which to the greatest extent allow realizing the concept of building a mechatronic system. This paper presents a microprocessor-based bench for measuring the current and angular velocity of a brushed DC motor as a function of armature voltage at no-load. The report shows the use of the bench to calculate the parameters of the DC motor and to evaluate its condition. An analysis is made of the condition of the engine and the modes in which it is most efficient.*
Keywords*:* MICROPROCESSOR STAND, DC MOTOR, MECHATRONIC SYSTEM, PULSE WIDTH MODULATION

1. Introduction

In modern mechatronic systems (robots, electric vehicles, machine tools, etc.) DC motors are widely used in the drive system where precise position control and high torque are required [1]. These motors allow easy control of direction of rotation and speed by using digital controllers, and driver, the control is done by pulse width modulation (PWM) method. The use of proportional-integral-differential (PID) controller in the control channel ensures the required response speed and minimum steady-state error [2]. This paper describes a digital DC motor test bench designed for training. The bench provides automatic measurement of motor current. The bench model also includes a tachometer as a speed sensor which is used in the feedback channel.

2. Results and discussion

In mechatronic systems DC motor directly provides rotary motion, and in combination with gears and racks or drums, and shafts can provide translational motion. The DC motor electrical equivalent diagram and the rotor body diagram without load are shown in Fig. 1 [3, 4].

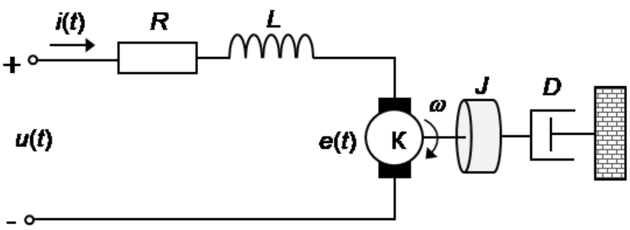

Fig.1 *Electrical diagram of DC motor without load.*

At the diagram R, Ω is armature resistance and L, H is armature inductance. The paper presents a test bench of DC motor with independent excitation and integrated tachometer. In this study, the system input is the source voltage u(t), V applied to the motor armature and the motor state parameters to be measured are the armature current i(t), A and the angular velocity of the shaft rotation ω(t), rad/s. We assume that the rotor and motor shaft are rigid and have an idling moment of inertia J, Kg m2. Furthermore, a viscous friction model is assumed, where the viscous friction coefficient is denoted by D, Nm s/rad. In the operator form, the motor performance can be described by the state parameters with two equations:

$$I(s) = \frac{U(s)-k\omega(s)}{Ls+R} \quad (1)$$

$$\omega(s) = \frac{ki(s)}{Js+D} \quad (2)$$

where, $U(s)$, $I(s)$and $\omega(s)$ are the Laplace transforms of $u(t)$, $i(t)$and $\omega(t)$.

In the equations (1), kω(s) is equal of the Laplace transform E(s) of the induced electromotive force (emf) at the motor armature e(t), V and ki(s) in the equation (2) is equal of the Laplace transform T(s)of the motor shaft torque T(t),Nm. The constant k,Nm/A is the torque constant. The equations describe the operation of the motor as a closed system with input signal U(s) and output signal ω(s), in which the error signal is ΔU(s)=U(s)-E(s). The block diagram of the engine model as a closed system at idling according to formulas (1) and (2) is shown in Fig. 2 [5].

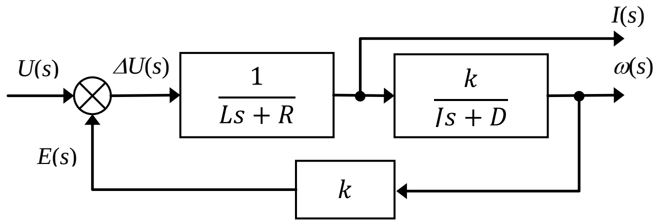

Fig.2 *Block diagram of the DC motor model as a close system*

The motor model is used to study the transient functions of the motor on its angular velocity

$$K_\omega(s) = \frac{\omega(s)}{U(s)} \quad (3)$$

and currents

$$K_i(s) = \frac{I(s)}{U(s)}. \quad (4)$$

The electromechanical T_m, ms and electromagnetic T_e, ms constants of the motor are determined by the two transition functions. Furthermore, this motor model is suitable for the study of PID controllers that improve its characteristics.

The DC motor test bench shown in Fig. 3 allows the motor speed to be controlled programmatically and its current and angular shaft speed to be measured.

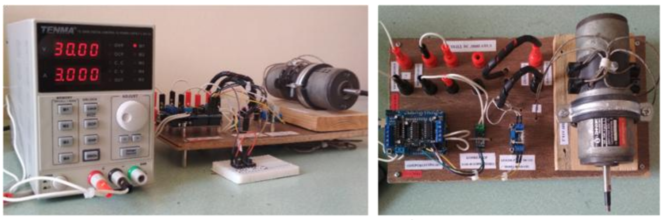

Fig.3 *Microprocessor test bench for DC motors.*

The composition of the DC motor test bench includes:

- DC motor type "PIVT-6 25/3 A";
- Microcontroller "Arduino" with driver for DC motor control "L293D";
- Current-voltage sensor "ACS712";
- DC-DC step-down converter "LM317";
- Multimeter, tachometer, wiring and calculator;
- Software to monitor and record motor status parameters on a PC.

The motor can be powered either directly from a DC voltage source or via the DC motor driver controlled by the microcontroller [6, 7]. The driver control is used to start the engine and adjust its speed. In this power supply option, the maximum motor supply voltage is limited to 12, V because the maximum current the driver can provide is 1, A. The stand allows the active resistance of the collector winding, the current and the collector voltage to be measured using an external multimeter. The motor characteristics according to the technical specifications are shown in Table 1.

Table 1: *Technical parameters of DC motor "PIVT-6 25/3 A".*

Specification	Units	Value
Nominal supply voltage	V	30
Torque continuously	Nm	0,110
Maximum torque < 10 min	Nm	0,225
Rotational speed at maximum torque	min^{-1}	3000
Maximum torque current	A	4,5
Torque constant	Nm/A	0,072
Electromechanical constant	ms	25
Electromagnetic constant	ms	2
Maximum allowable pulse current	A	20
Tachometer		
Electromotive force constant	$V/10^3 min^{-1}$	3
Pulsations	%	5

The paper shows experimental results of calculating of the emf E, V, the mechanical power P_{out}, W, the coefficient of performance (COP) η, the engine torque T, Nm and its boost factor k_{mot}. The measurements were made with the engine directly powered. The block diagram of the bench under direct power supply is shown in Fig. 4.

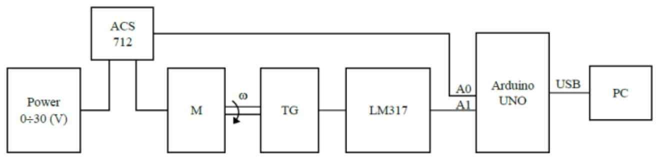

Fig.4 *Block wiring diagram of DC motor test bench..*

In the diagram "M" is the motor, "TG" is the tachometer and "PC" is the personal computer. The motor is powered by an adjustable rectifier with an LED display showing the output voltage and current consumption. It provides constant voltages from 0 to 30, V DC and a maximum current of 3, A. The DC-DC converter reduces twice the voltage of the TG to be input to the microcontroller.

Results of the measured and averaged values of the DC motor "PIVT-6 25/3 A" current and angular shaft speed for five collector voltages U are presented in Table 2. The data characterize the steady-state operation of the motor.

In Table 2 I and ω are the measured values of shaft current and speed, and I_{aver} and ω_{aver} are the calculated averaged values.

In addition to measuring engine condition parameters, the stand also allows the active resistance of the manifold to be measured using an external multimeter. The resistance is measured for different angular positions of the motor rotor and the average value is used for subsequent calculations. The measured manifold resistance values R_{eli} are presented in Table 3.

The average value of the collector winding resistance is calculated by the formula:

$$R_{aver} = \frac{\sum_{i=1}^{n} R_{el\ i}}{n} \qquad (5)$$

where, n is the number of measurements.

Table 2: *Measured and averaged values of DC motor "PIVT-6 25/3 A"current and shaft speed in steady state.*

U=10, V		U=15, V		U=20, V		U=25, V		U=30, V	
I, A	ω, rpm	I, A	ω, rpm	I, A	ω, rpm	I, A	ω, rpm	I, A	ω, rpm
0,33	646,2	0,29	1179,9	0,32	1791,1	0,36	2290,0	0,37	2811,1
0,32	678,2	0,37	1162,9	0,38	1723,0	0,37	2277,4	0,32	2872,4
0,27	659,7	0,29	1187,4	0,31	1782,4	0,35	2283,1	0,34	2819,6
0,35	628,9	0,31	1231,1	0,32	1776,4	0,34	2305,4	0,36	2871,1
0,33	659,7	0,32	1233,6	0,36	1711,1	0,32	2332,1	0,35	2788,8
0,27	682,9	0,33	1179,9	0,34	1774,2	0,33	2347,5	0,29	2883,4
0,32	615,7	0,36	1162,0	0,31	1757,8	0,35	2345,9	0,35	2808,6
0,31	643,7	0,32	1178,0	0,36	1738,4	0,35	2327,4	0,39	2841,6
0,26	701,8	0,29	1222,6	0,30	1804,4	0,36	2307,3	0,34	2833,4
0,27	638,0	0,33	1237,4	0,30	1752,0	0,36	2287,2	0,28	2851,0
0,32	627,6	0,31	1185,8	0,37	1730,8	0,35	2270,2	0,33	2859,2
0,33	686,7	0,35	1168,9	0,35	1794,3	0,38	2264,9	0,35	2807,0
0,27	666,0	0,29	1173,0	0,34	1727,1	0,33	2277,7	0,32	2889,0
0,29	612,9	0,28	1218,2	0,32	1758,8	0,33	2305,7	0,37	2815,8
0,27	669,4	0,3	1243,3	0,28	1807,8	0,34	2335,8	0,39	2871,4
0,31	687,3	0,3	1190,2	0,32	1721,7	0,32	2359,4	0,38	2796,7
I_{aver}	ω_{aver}	I_{aver}	ω_{aver}	I_{aver}	ω_{aver}	I_{aver}	ω_{aver}	I_{aver}	ω_{aver}
),301	656,5	0,315	1197,1	0,33	1759	0,346	2307	0,346	2838,8

Table 3: *The measured manifold resistance values.*

$R_{el\ i}$, Ω																	
4,2	4,1	4,8	4,0	5,9	4,6	4,2	4,0	4,1	7,0	7,0	5,5	6,8	7,8	6,0	13,3	4,8	8,8

The average value of the collector winding resistance according to Table 3 is R_{aver} = 5,84, Ω.

The following formulas are used to determine the steady-state DC motor parameters [8, 9]:

$$E = k\omega_{aver} \qquad (6)$$

$$P_{out} = I_{aver} E \qquad (7)$$

$$P_{in} = I_{aver} U \qquad (8)$$

$$\eta = \frac{P_{out}}{P_{in}} \qquad (9)$$

$$T = kI_{aver} \qquad (10)$$

$$k_{mot} = \frac{\omega_{aver}}{U} \qquad (11)$$

where, P_{in}, W is input power;

P_{out}, W is output motor power.

The calculated motor parameters for different input voltages are shown in Table 4.

Table 4 *The measured manifold resistance values.*

	U =10, V	U =15, V	U =20, V	U =25, V	U =30, V
E, V	4,95	9,03	13,27	17,40	21,40
ω, rpm	656,50	1197,0	1722,0	2307,0	2838,70
ω, rad/s	68,75	125,35	180,33	241,59	297,27
P_{in}, W	3,01	4,73	6,60	8,66	10,37
P_{out}, W	1,49	2,84	4,38	6,02	7,40
T, Nm	0,02	0,02	0,02	0,02	0,02
η	0,50	0,60	0,66	0,70	0,71
k_{mot}	6,87	8,35	9,02	9,66	9,91

The obtained results show that at low speed the boost factor and the efficiency of the engine are significantly lower than at high speed. Also at 30, V supply the motor fails to reach its maximum speed which according to technical parameters is 3000, rpm. This is due to additional electrical losses in the manifold and mechanical losses from viscous friction. This is evidenced by the calculated manifold winding resistances R_{calc} in dynamic mode at different supply voltages, which are 16,76 Ω, 18,96 Ω, 20,41 Ω, 21,96 Ω and 24,87 Ω respectively. The winding resistance during motor operation is calculated using the formula:

$$R_{calc} = \frac{P_{in} - P_{out}}{I_{aver}^2} \quad (12)$$

The calculated resistances differ significantly from the measured average resistance of 5,84 Ω and increase with increasing of motor speed.

3. Conclusion

The study of the principle of operation and ways of modeling electric motors is the basis for the creation of electromechanical systems with automatic control. The created stand is a tool for visual representation of brushed DC motor operation. Through it is possible to collect experimental data on the state parameters of the motor in different modes and by processing the accumulated statistics to determine its technical parameters.

4. References:

1. D. Shetty, R. A. Kolk, *Mechatronics System Design*(Cengage Learning, USA, 2011), 2nd edition, p. 504.
2. Abdulameer, M. Sulaiman, M.S.M Aras, D. Saleem, "Tuning methods of PID controller for DC motor speed control", Indonesian Journal of Electrical Engineering and Computer Science **3**(2), pp. 343–349 (2016).
3. N. S. Nise, *Control System Engineering* (John Wiley & Sons, New York, 2015), 7th edition, p. 943.
4. P. Kaltjob, *Mechatronic Systems and Process Automation: Model-Driven Approach and Practical Design Guidelines* (CRC Press, 2018), p. 467.
5. Deepti Singh, Brijesh Singh, Nitin Singh, *Performance Indices Based Optimal Tunining Criterion for Speed Control of DC Drives Using GA*, International Journal of Power Electronics and Drive System (IJPEDS) Vol. 4, No. 4, December 2014, pp. 461~473 ISSN: 2088-8694.
6. M. Gavran, M. Fruk, G. Vujisić, "PI controller for DC motor speed realized with Arduino and Simulink", 2017 *40th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, (Opatija, Croatia, 2017), pp. 1557–1561.

a. N. Hamoodi, R. A. Mohammed, S. A. Hamoodi,"Automatic speed control of DC series motor by using Arduino", PrzeglądElektrotechniczny**3**, pp. 137–141 (2023).

7. R. C. Chourasia, N. Verma, P. Singh, S. Kant, "Speed control of DC motor using PID controller", Global Journal of Technology and Optimization**13**(1), pp. 1–4 (2022).
8. N. Thomas, Dr. P. Poongodi, "Position control of DC motor using Genetic algorithm based PID controller", *Proceedings of the World Congress on Engineering (WCE)* ***II****, (1-3 July, London, U.K., 2009)*.