



Dual Electromagnetic Retarder Control System for Tuning Internal Combustion Engines

Victor Busher

Dept. Electromechanical Systems with Computer Control
Odessa National Polytechnic University
Odessa, Ukraine
victor.v.bousher@gmail.com
<https://orcid.org/0000-0002-3268-7519>

Vasily Horoshko

Dept. Electromechanical Systems with Computer Control
Odessa National Polytechnic University
Odessa, Ukraine
vas.goroshko@gmail.com
<https://orcid.org/0000-0002-7265-2513>

Abstract. A preliminary analysis and synthesis of structural, functional diagrams of the control system of two electromagnetic retarders connected to the driving wheels of the car, to ensure the adjustment of the fuel system of the internal combustion engine, was performed. When developing the system, the mechanical connection of the wheels through the gearbox and the differential bridge was taken into account. For precise adjustment of the ignition timing and fuel mixture composition, the control system of electromagnetic retarders must operate in two modes – start to the desired speed of the internal combustion engine with simultaneous rotation of both wheels with a minimum total load torque and stabilize this speed throughout the gas pedal position range. It is shown that to solve the task, the control system can be built both with two PI-wheel speed controllers with a common master signal, and with a more complex dual 2-circuit system with current and speed control. Also, taking into account the non-linear dependence of the torque of electromagnetic clutches on current and speed, fractional-integral regulators can be applied. The final decision on the regulatory structure will be made after testing the control system. In the future, we plan to upgrade the system for four-wheel drive cars.

Keywords — dual electromagnetic retarders, PI-regulator, internal combustion engine, open differential, microprocessor control system.

I. INTRODUCTION

Inductive brakes or retarders (fig. 1) are widely used in cargo and passenger transport, industry (wind generators, lifts), emergency braking systems, as well as in test benches [1]. In many modern trucks and buses, in addition to the main brakes, you can find an additional braking system (mountain brake) using a retarder. The principle of operation is based on the conversion of mechanical rotational energy into heat due to the generation of Foucault currents, which arise in a massive metal conductor as it moves in a magnetic field that is created by coils. The inductive brake consists of a stator and a pair of rotors rigidly connected to each other. A stator is series-connected electromagnets, in which a powerful magnetic field arises under the action of an electric current.

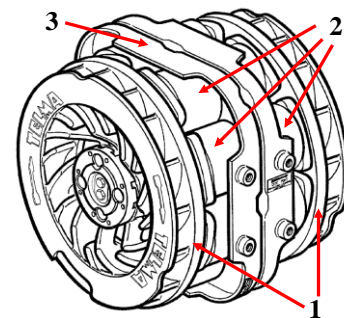


Fig. 1. Image of electromagnetic retard, where 1 – metal disk (rotor) with fan, 2 – electromagnets, 3 – trunk

Magnetic field and Foucault currents create torque [2], which tends to stop the rotor while simultaneously warming it. The special shape of the rotors helps to remove excess heat using the created air flow. Therefore, when placing a retarder, it is very important to provide good ventilation to remove hot air.

Due to its advantages of the rotary eddy-current brake can be applied not only in the systems where it needs to slow down the rotational speed. So, in the authorized center for servicing sports cars of various classes participating in international rallies, two retarders are used to brake the drive wheels. Unlike most production cars, engine tuning of sports cars should be performed with high accuracy for the entire range of speed and torque of the internal combustion engine for each point of the three-dimensional surface depending on the ignition angle on speed and fuel supply (fig. 2). At the same time, it is necessary to select the composition of the fuel mixture (the ratio between the amount of fuel and air) to ensure maximum torque and minimum fuel consumption [3, 4]. To carry out the adjustment of the internal combustion engine, retarders are installed instead of wheels and must ensure that the wheels work at a given speed and torque.

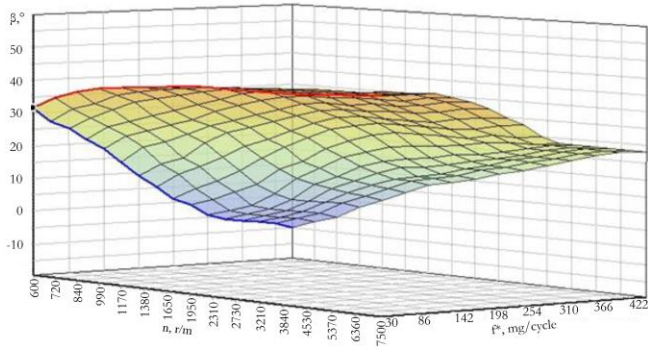


Fig. 2. Ignition timing as a function of speed and quantity of fuel per cycle

To ensure such a setup, a stand was created by the masters of the service center, which includes two, and later four, retarders TELMA fixed to the hubs instead of the driving wheels of the car. Torque sensors are built into the retarder hitches; they measure up to 10 times per second and provide data transmission using the RS232 serial protocol (9600 bod). Also were used infrared speed sensors with a resolution of 10 pulses per revolution. The control system synchronized the wheel speeds by changes the current of the retarders.

However, tests have shown the inefficiency of the system. Synchronization took a long time (tens of seconds), impenetrable changes in the torque and speed of the internal combustion engine led to oscillations.

In this regard, the task of studying the system and the synthesis of regulators, which will provide fast (not longer than 1...2 s) wheel synchronization and fast transitions from one operating point to another, has arisen.

II. MODELLING OF SYSTEM

The mathematical model of the transition of the driving torque from the engine shaft to the wheels includes several basic units. Given that the purpose of the work is not to study internal processes in internal combustion engines, we will build a model in the SimPower System, and instead of internal combustion engines we use the basic model of an induction motor, increasing the rotor resistance of which will provide approximate similarity between the operating ranges of the mechanical characteristics of the internal combustion engine and an induction motor. Also, to reduce the effect of electromagnetic transients in an induction motor, we will only change the load moment on the shaft, and not the frequency and amplitude of the input voltage.

Also, in the mathematical model of the mechanical part of the car the following assumptions are made:

- Elastic bonds and losses in the clutch, gearbox and driveshaft combined into one element.
- Power losses and elastic connections in the differential are not taken into account.

With the proposed assumptions, a model was built in Simulink (fig. 3). It consists of four main blocks: a drive unit (asynchronous motor), an open differential and two retarder control systems.

From the motor shaft, the power is transmitted to a symmetric differential, which is described by a system of equations [5, 6]:

$$\begin{cases} \frac{d\omega_L}{dt} J_L = T_L - T_{bL} + \mu T_d, \\ \frac{d\omega_R}{dt} J_R = T_R - T_{bR} - \mu T_d, \\ \frac{T_d}{2} = T_L = T_R, \\ \frac{dT_{ru}}{dt} c_u = \omega_h - \omega_L - \omega_R, \\ T_{rv} = b_v (\omega_h - \omega_L - \omega_R), \\ T_d = T_{ru} + T_{rv}. \end{cases} \quad (1)$$

where $J_L, J_R, \omega_L, \omega_R, T_L, T_R, T_{bL}, T_{bR}$ – moment of inertia, angular velocity, torque and brake torque of the left and right wheel axles, respectively; μ – load asymmetry factor; T_{rv} – torque of the viscous friction driveshaft; T_{ru} – elastic torque from the engine to the differential; T_d – driveshaft torque; c_u, b_v – coefficient of elastic and coefficient of viscous friction respectively.

Since the drive axle shafts are not connected to each other, they can rotate at different speeds. This asymmetric is expressed by the constant value $\pm\mu T_d$ in the system of equations (1), although during real operation of the differential this value and sign can vary.

According to the system of equations (1), the block “Differential” was built (Fig. 4). The inputs of this block are the angular velocity of the motor and the brake torque from retarder “TbL” and “TbR”. The outputs are the angular velocities of the axles “ ω_L ” and “ ω_R ”, as well as the torque of the differential “Torq”.

The value of the brake torque is controlled by the control system, which is represented by the “Left retard control” and “Right retard control” blocks (fig. 5a and 5b). The input speed of the axle (“ ω_L ” or “ ω_R ”) and the reference signal “ ω_{ref} ” are inputs of this block. Outputs are the signals “UrL” or “UrR” and braking torques (“TbL” or “TbR”).

The model compares different control systems to stabilize speed.

A single-loop system with a PI-speed controller is used to control the left axle, and a double-circuit system with a PI-speed controller and a relay current regulator is used for the right axle. Measurements and transmission of control signals is carried out taking into account the quantization of the level and time by units Quantizer and Zero-Order Hold.

Current transients in the induction brake coil are approximated by transfer function:

$$W_c(s) = \frac{1}{0.1s + 1}. \quad (2)$$

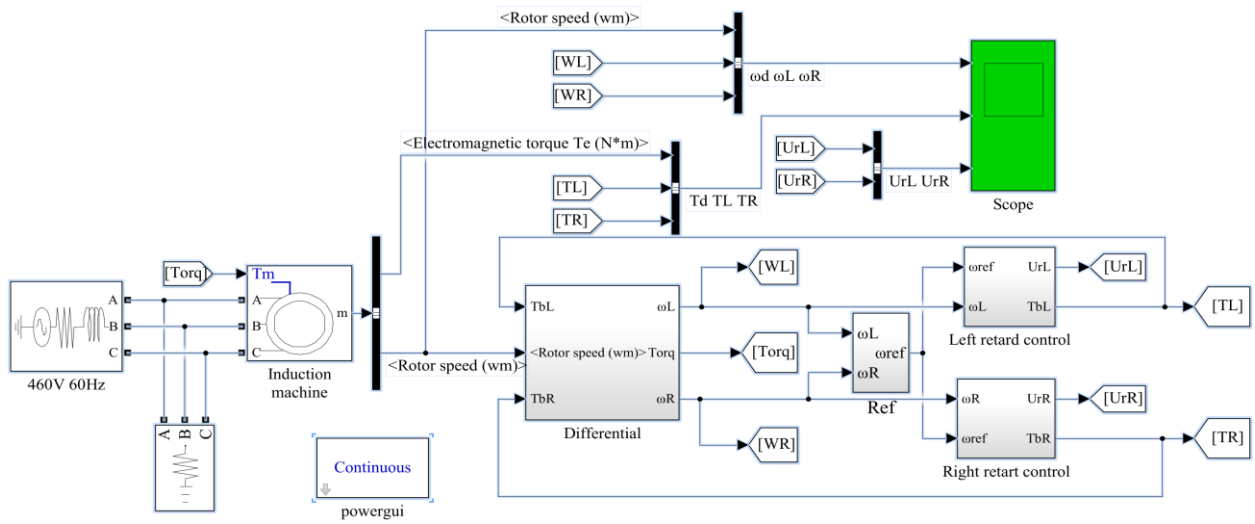


Fig. 3. Object model and control system

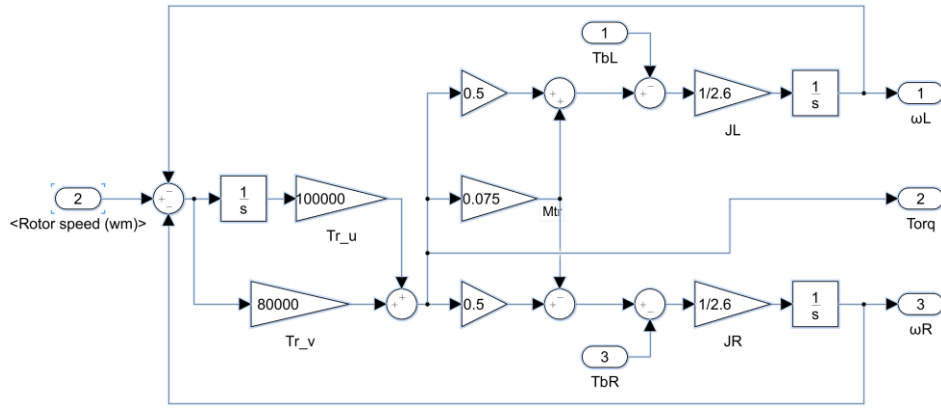


Fig. 4. Model of an open differential

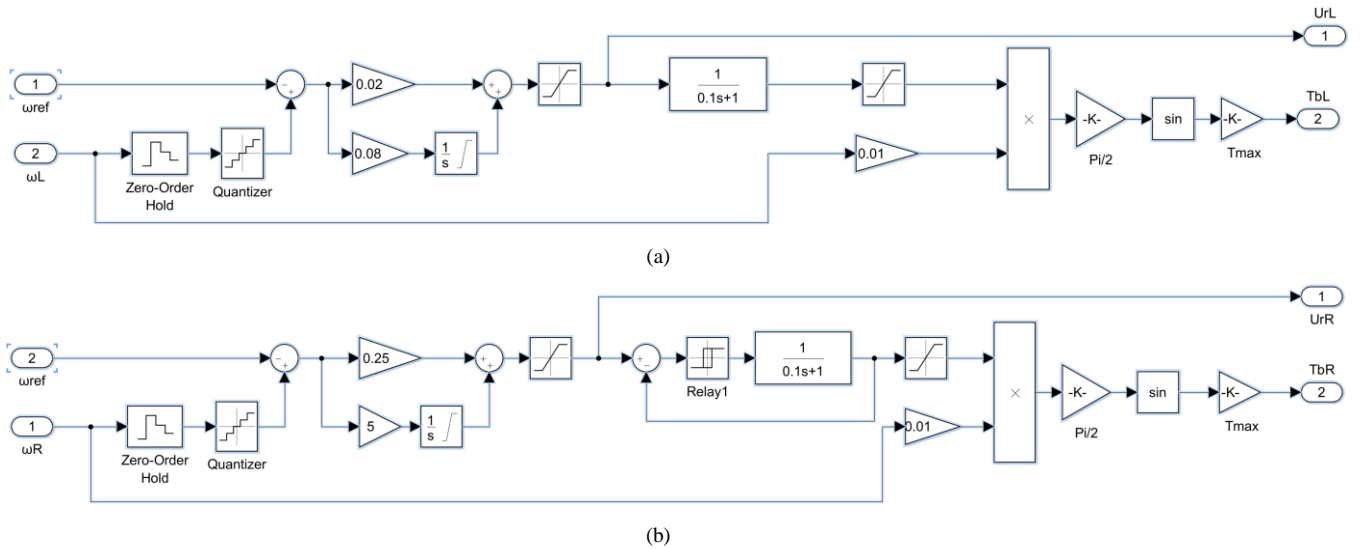


Fig. 5. Control system for – (a) left retard (b) right retard

The nonlinear dependence of the moment of the induction brake on the current and speed is approximately described by the function:

$$T_b = T_{\max} \sin\left(\frac{\pi}{2} i_b k \omega_b\right), \quad (3)$$

where T_{max} – maximum brake torque; i_b, i_n – instantaneous value and rated brake current; ω_b, ω_n – angular and rated speed.

The "Ref" block (fig. 6) serves for the speed reference. It provides two modes: calibration and stabilization. In the calibration mode, the engine is accelerated by the operator, but the rotational speed of the two axes should be approximately equal. To do this, the value of the reference signal is calculated by the expression:

$$\omega_{ref} = \frac{\omega_L + \omega_R}{2} + \Delta, \quad (4)$$

where ω_{ref} – speed reference signal; Δ – feed-forward constant, selected depending on the acceleration of the axes so that by the end of transients the speeds are approximately the same, and the moments are close to zero.

In the mode of speed stabilization, the reference signal is calculated by the block "Stair Generator" and then transmitted to the corresponding control systems. The angular velocity of the axle must be kept constant regardless of the power supplied from the engine. The bias on the natural characteristics of an asynchronous motor simulates an increase in the fuel supply to the internal combustion engine, but it eliminates the influence on the system of electromagnetic transients that would occur when regulating the voltage and/or frequency while maintaining a constant motor speed.

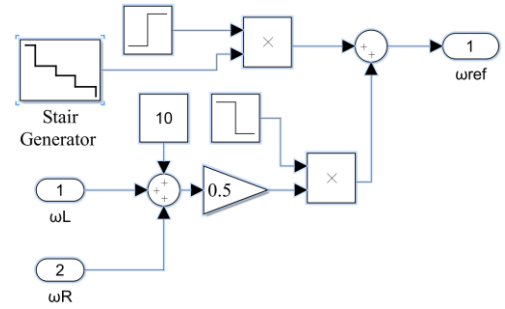


Fig. 6. Speed reference signal

III. MODELLING RESULTS

The simulation results are presented in Fig. 7. It shows the speed transients for the left axle – " ω_L ", the right – " ω_R " and the engine – " ω_d ", the moment of the left axle – " TL ", the right – " TR " and the engine – " Td ". " UrR " is the current reference for the right brake and the value " UrL " is the duty cycle of the PWM voltage for the left axle.

As can be seen from Fig. 7, during the first second the engine accelerates and the speed of the axles is calibrated. Since 15% more torque is transmitted to the left axle, it picks up speed faster. At a certain value of speed, the left retarder begins to slow down the axle. The right retarder generates a torque when the angular velocity of the left axle becomes less than the right.

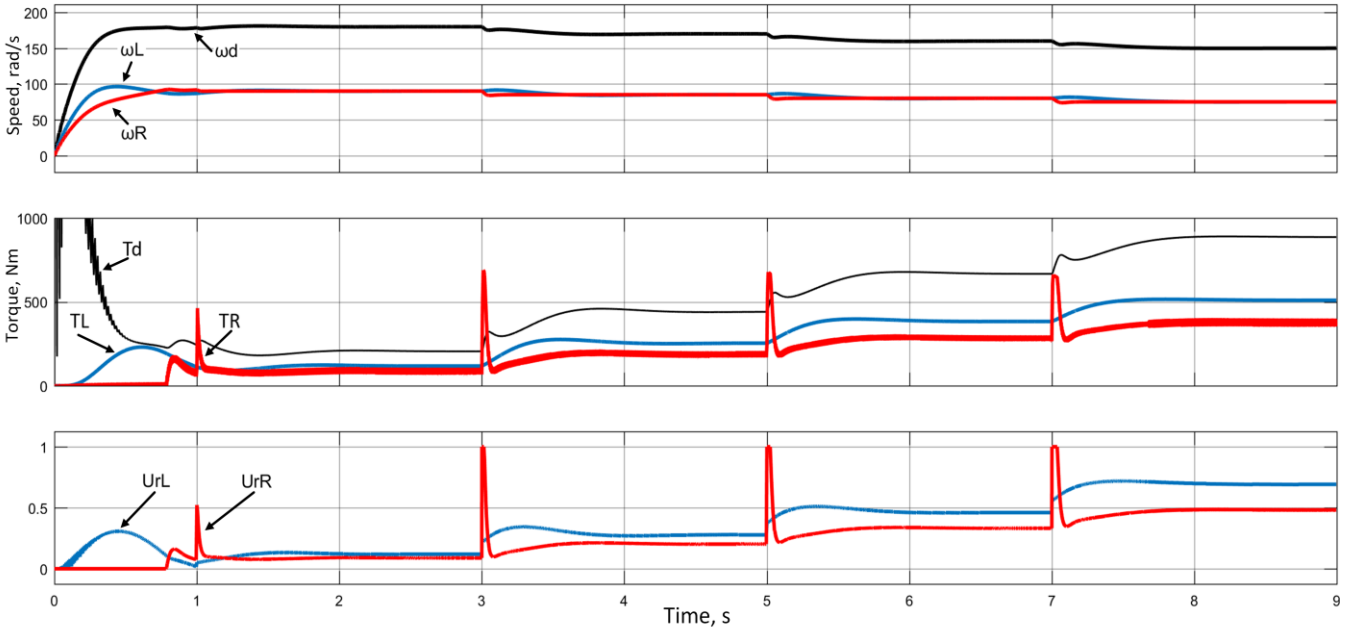


Fig. 7. Transients of axle and engine speed, torque, controller signals.

Starting from the first second, the reference signal goes into stabilization mode with a value of 90 rad / s. After 3 s – 85 rad / s, 80 rad / s at 5 s and 75 rad / s at 7 s. In all cases, a dual-circuit right brake system provides a better quality transient than a single-circuit left brake. Since the time of the first matching of the right axle is 0.04 s, the left one is 0.5 s. However, in both cases, satisfactory results were obtained from the point of view of the task, provided that a speed sensor with a resolution not worse than 0.1 revolutions per minute and a period of quantization no more than 0.02 s were used.

IV. CONCLUSION

Produced preliminary synthesis and analysis of the control system for induction brakes to configure the fuel system of an internal combustion engine. For precise adjustment of the ignition timing and the composition of the fuel mixture, the control system for electromagnetic loads must operate in two modes – calibration and stabilization. It is shown that to solve the task, the control system can be built both with a single-loop system with a PI-speed controller, and a dual-circuit with an inner relay current controller. The final decision on the structure of the

regulators will be made after testing the control system. In the future, if the task of automating the tuning process is given, taking into account the non-linear dependence of the torque of electromagnetic retarders on current and speed, fractional-integral regulators can be used that provide high performance with a small overshoot [7].

REFERENCES

- [1] C. Y. Liu, K. J. Jiang and Y. Zhang, "Design and Use of an Eddy Current Retarder In an Automobile," *International Journal of Automotive Technology*, vol. 12, No. 4, 2011. pp. 611–616. doi: 10.1007/s12239-011-0071-3
- [2] S. Anwar "A parametric model of an eddy current electric machine for automotive braking applications," *IEEE Transactions on Control Systems Technology*, vol. 12, issue 3, 2004. pp. 422–427. doi: 10.1109/TCST.2004.824293
- [3] V. A. Kalmakov, A. A. Andreev *The Ignition System of a Car*. Cheljabinsk, 2014.
- [4] A.H.Kakae, M. H. Shojaefard and J.Zareei "Sensitivity and Effect of Ignition Timing on the Performance of a Spark Ignition Engine: An Experimental and Modeling Study" *Journal of Combustion*, 2011. pp. 1–8. doi: 10.1155/2011/678719
- [5] R. Morselli, R. Zanasi, G. Sandoni "Detailed and Reduced Dynamic Models of Passive and Active Limited-slip Car Differentials" *Mathematical and Computer Modelling of Dynamical Systems*, vol.0, No 0, 2004. pp. 1–20.
- [6] V. P. Tarasik, O. V. Puzanova, V. I. Kurstak "Differential drives modeling of mobile machines driving wheels" *Vestnik Belorussko-Rossiyskogo universiteta*, vol. 3, No. 24, 2009. pp. 1-12.
- [7] V. Busher, L. Melnikova, V. Horoshko "Synthesis and implementation of fractional-order controllers in a current circuit of the motor with series excitation," *Eastern-European Journal of Enterprise Technologies*, vol. 2, No. 2, 2019. pp. 63–72. doi: 10.15587/1729-4061.2019.161352