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Operation of a drive system using two independent PMSM motors in passenger lift door drives

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Abstract: A brushless direct-current (BLDC) and permanent-magnet synchronous motors (PMSMs) with permanent magnets are characterised by the highest operating parameters among all electric motors. High dynamics and the possibility of controlling their work improves the operating parameters of the drive system and reduces the operating costs of such a device. The high cost of these machines associated with the complexity of their construction is a serious barrier to increasing their range in small propulsion systems, where lower energy consumption does not give such spectacular financial profits. To reduce costs, manufacturers often limit the variety of manufactured engines so that by increasing the volume, the unit cost of the device can be minimised. This is often hindered by the implementation of projects deviating from standards where it is necessary to use drive systems of different power. The solution to this problem could be the use of two independent drive systems working in strict correlation to ensure sufficient operating parameters of the device. The article presents a method of controlling a drive system in which two propulsion systems with PMSM engines were used. These devices are communicated with each other by a serial bus, by means of which data necessary for the correct operation of motors connected by a drive belt are transmitted. Since these machines affect both the working machine and each other, it is necessary to optimise such a system so as to avoid excessive oscillation of the drive torque in the system.

Key words: door drive, dual drive system, PMSM motor

1. Introduction

The willingness to reduce energy consumption and increase the efficiency of devices prompts producers of everyday devices to use advanced and modern control structures. Such actions can improve their work and enable the operation of these systems with very high efficiency. The falling costs of semiconductor systems and their increasing efficiency and specialisation mean that advanced control algorithms do not have to be reserved for applications requiring high inverter power, where increased financial outlays for the construction of the control system are low compared to the entire cost of the drive system. Dissemination of fast microcontrollers integrating in their structure digital signal processing (DSP) cores made it possible to implement demanding high computing powers, vector control algorithms in low power drives while maintaining the criterion of low investment costs. In low power applications, we can also observe a reduction in the amount of energy consumed in the cycle, but the absolute values of savings are not as spectacular as in the case of high power drives. The use of advanced control structures for small propulsion systems aims to improve the dynamic and control properties of the drive, which in many applications is crucial to meet the requirements of their end users.

An additional advantage of brushless motors compared to standard DC drives is a significant reduction of potential failure nodes and prolonging their usage time [2].

2. The use of a synchronous motor in a drive system with controls speed curve

The basis for the work of many drive systems is the appropriate, in accordance with the parameters set by the user, trajectory of the motion of the drive system of the so-called driving curve. It can clearly be seen that this curve is characteristic of many applications of electric drive systems. During its implementation, we distinguish two speeds: travel speed (V_t) and arrival speed (V_a). In addition, it is necessary to parameterise the acceleration (A_c) and deceleration (D_c) so as to provide the acceleration and braking dynamics appropriate for the industrial process.

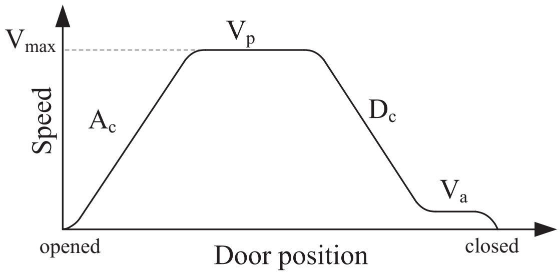


Fig. 1. Cabin door speed curve

Due to the desire to increase the efficiency of the process, and at the same time the need to ensure high stopping precision, it is necessary to maintain a high ratio of the travel speed to the arrival speed (V_t/V_a) of approximately 20 : 1 to 100 : 1 [1, 7].

The thrust torque on the motor shaft is the sum total of the torque coming from the movement resistance as well as the specific characteristics of the working machine.

The most commonly used drive system implementing the driving curve contains in its structure an induction motor, which in more advanced solutions is powered by a specialised frequency converter. This system is characterised by relatively high operating parameters, while maintaining an acceptable price level of the entire device.

On the example of the drive system of the passenger lift cabin door, it can be stated that the big advantage of induction motors is their ability to work in the direct drive system due to the relatively low rated speed of the motor. This solution is cheap, quiet and provides the right moment when moving the cabin doors.

Unfortunately, the specificity of the work of such a system forces the drive motor to create a pressing moment in the phases of the door's full opening and full closing, which in the case of using an induction motor requires the delivery of a significant portion of energy throughout the lift's standstill. This has a very adverse effect on the energy balance of the drive system, significantly increases operating costs and is the cause of frequent overheating of the drive.

A much better solution is the use of a drive system with a PMSM engine, whose energy parameters, especially in the low speed range, are significantly better than the commonly used induction motor.

In addition to improving the quality of operation, the amount of energy consumed by this type of propulsion system is significantly reduced. The use of a permanent magnet motor significantly reduces operating costs and allows for short-term amortisation of increased expenditures incurred for the purchase of an advanced, and therefore more expensive, drive system [1, 6].

3. Control problems

The use of an efficient, standardised low power drive, for a wide range of output parameters, encounters limitations related to its maximum power and, consequently, a decrease in operating parameters, such as maximum speed or work dynamics.

There are two solutions to the problem of insufficient performance of such a drive system. The first, seemingly the best, is the use of a more powerful propulsion engine and a modified torque transmission system, and the second: the use of two drive motors mechanically coupled with each other, e.g. by a drive belt. The second, seemingly more complicated and expensive method is in practice often more beneficial considering the economic conditions of the production process. The reason why a better solution for a manufacturer is the use of two standard drive systems is the unification of products within one group and a significant simplification of subsequent service. Having a wide range of drive systems is very inefficient from an economic point of view and leads to the need to maintain stock levels and service reserve of many series of equipment types.

In practice, the use of two drive motors working on the so-called "common shaft" is relatively common and has successfully been used for many years in unregulated systems with induction motors. In some applications requiring more advanced control of the driving curve, an appropriately oversized inverter allows control of two induction motors operating on a common shaft, which from the point of view of the control system are treated as one induction motor with increased power.

The willingness to replace the existing control structure based on the inverter and the induction motor with the synchronous motor system puts before the constructors the need to develop a way to control synchronous motors so that they work with the same drive torque.

4. Operation of motors with torque coupling

The work of synchronous motors mechanically connected to each other and the working machine is much more problematic than the popular induction motors. To determine the cooperation conditions of such devices, it is necessary to analyse the influence of control and motor parameters on the value of their electromagnetic torque T_{em}. Because the developed solution is a synchronous motor with permanent magnets, it is precisely its properties that will be analysed. The formula for the electromagnetic moment of a synchronous motor can be written as follows [3, 8]:

$$T_{em} = \frac{3}{2} p_p \left(\psi_{sd} I_{sq} - \psi_{sq} I_{sd} \right). \tag{1}$$

Assuming the cooperation of identical machines, the condition for the equality of electromagnetic moments is to assume the equality of the current components of both machines in the q-axis.

$$I_{q1} = I_{q2}, \tag{2}$$

Fulfilling the conditions of equality of the current components in the $q-$axis is a condition sufficient for the operation of drives with the same electromagnetic torque in the first control zone. This allows for proper cooperation of PMSM electric machines connected together.

Additional analysis should include the work of such a system connected by a link with a certain degree of flexibility – a transmission belt. Such analysis is most easily carried out using the numerical analysis tool, e.g. the Matlab-Simulink package.

5. The proposed solution

To facilitate the commissioning and configuration of a drive system consisting of two separate inverter-motor sets, a control structure was chosen, in which all operating parameters and speed control are carried out in only one controller, and the other serves only as an auxiliary one. From the point of view of the control system and the user, the use of the second drive system does not change anything in the device configuration process (Fig. 2).

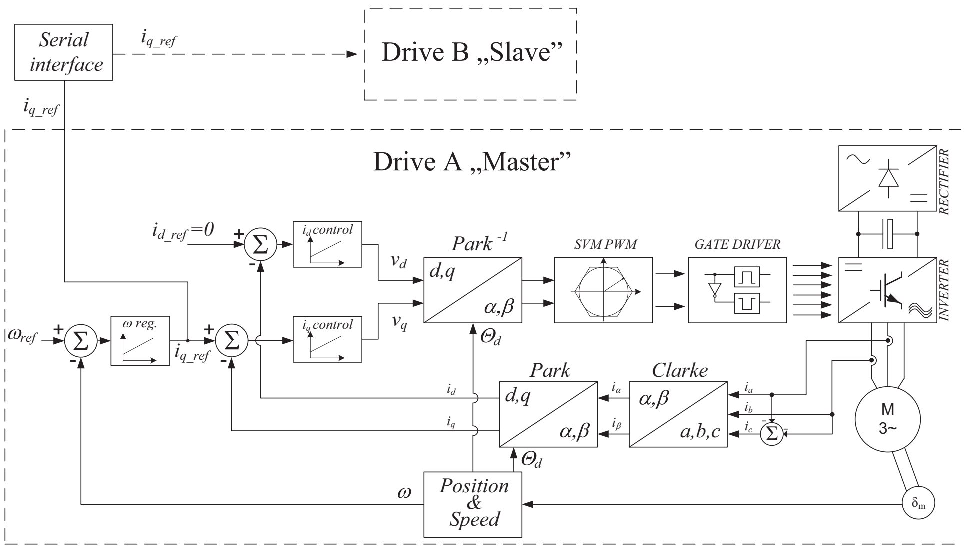


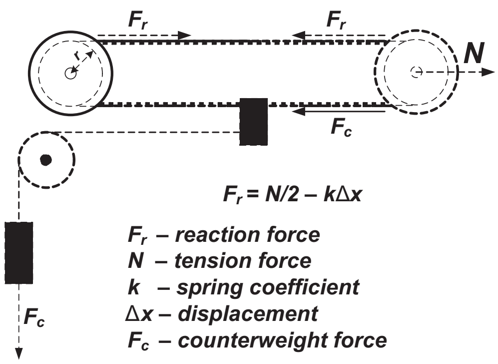
Fig. 2. The control structure of the propulsion system consisting of two drives dependent on vector-driven PMSM motors

The operation of the drive is based on the Master-Slave relationship, in which one drive system is the Master unit and the other plays the auxiliary role in generating the drive torque.

The creation of the component value I_q of the stator current identical to that generated by the Master drive control algorithm by the inverter of the Slave controller will make the drives produce the same electromagnetic torque in accordance with the trajectory stored in the Master controller memory.

6. Model research

To analyse the correctness of the theoretical assumptions, a simulation model was prepared using the Matlab-Simulink package. This model consists of two independent propulsion systems connected by a transmission belt, whose tension represents the coefficient of elasticity "k" (Fig. 3).



Simulation data
Nominal torque of a single motor (a, b): 3.0 Nm
Inertia: 0.09 kg·m^2
Door weight: 400 kg
Diameter of a drive wheel: 3 cm
Counterweight mass: 2 kg

Fig. 3. Diagram of the drive transmission system in the cabin door drive system

Standard elements from the SimPowerSystems library were used to build the drive system model – they are AC6 type drive systems equipped with a PMSM synchronous motor with parameters modified to the actual values of the drive motor. They were powered from a 240 VAC mains power supply with parameters similar to the actual "Power grid" power supply system. Communication between the drive systems takes place via a serial bus, which introduces some delay represented by the "Serial Transmission Delay" block (Fig. 4). The static moment is exerted only by the counterweight represented by the "Counterweight" block of torque. The numerical value in this block determines the torque exerted by the counterweight on the shaft of each drive.

Drive "A" is equipped with a "Speed Controller", which generates a control signal for the vector torque regulator "VECT" (Fig. 5). At the same time the output of the "Torque*" regulator is the source of the point set for the torque regulator "B" (Fig. 6).

The drive system "B" is deprived of a speed controller block and is based on the torque setpoints developed by the speed controller of the "A" drive.

Because the mechanical coupling of the shafts is made between the drives using a flexible connector (elastic belt), we can assume that the change in the relative angle of the shafts (Θ_A, Θ_B)

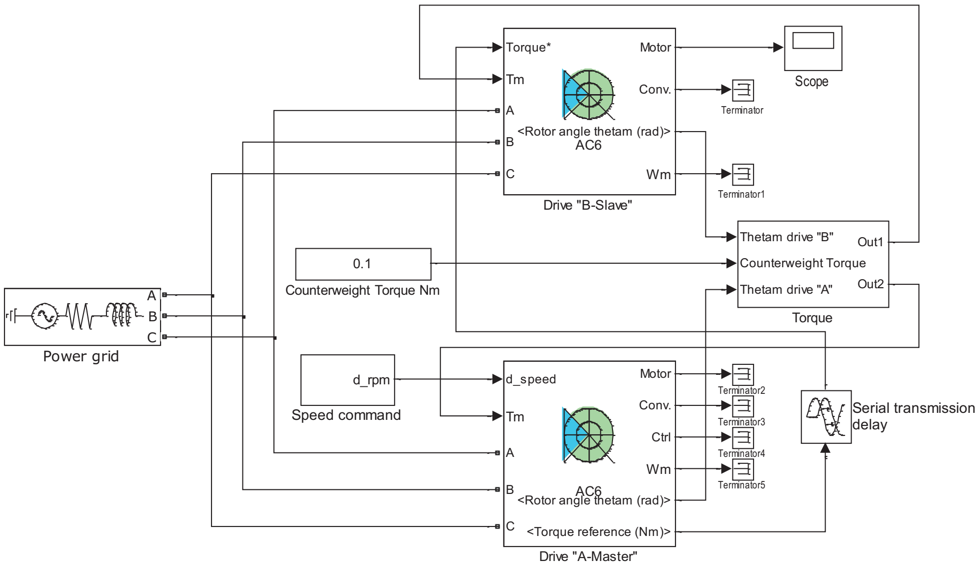


Fig. 4. Simulink model of Master-Slave dual drive system

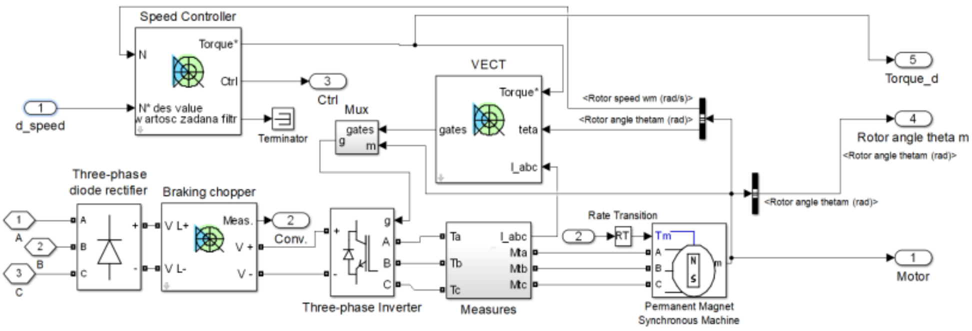


Fig. 5. Simulink model of Master drive "*A*" subsystem

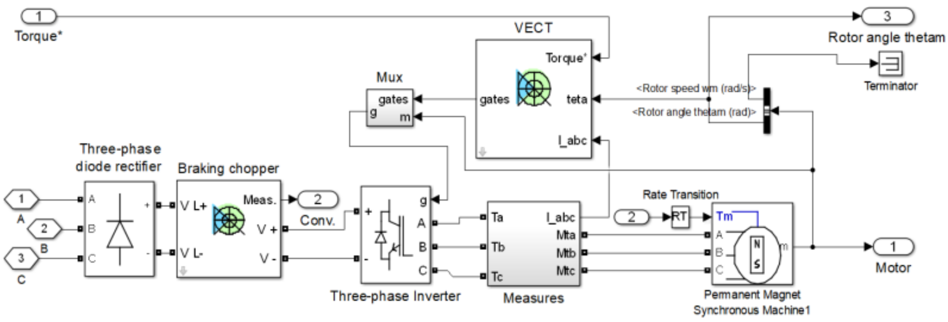


Fig. 6. Simulink model of Slave drive "*B*" subsystem

creates a torque of mutual interaction (T_A, T_B), proportional to the elasticity ratio "k" and the "Angle offset" position difference of the shafts and the weight of the counterweight.

$$T_A = T_c + (\Theta_A - \Theta_B) \cdot k, \tag{3}$$

$$T_B = T_c + (\Theta_B - \Theta_A) \cdot k, \tag{4}$$

$$T_A + T_B = 2T_c\,. \tag{5}$$

The sum of these torques is constant and equal to the moment exerted by the $2T_c$ counterweight. A model of such interaction of drives is shown in Fig. 7.

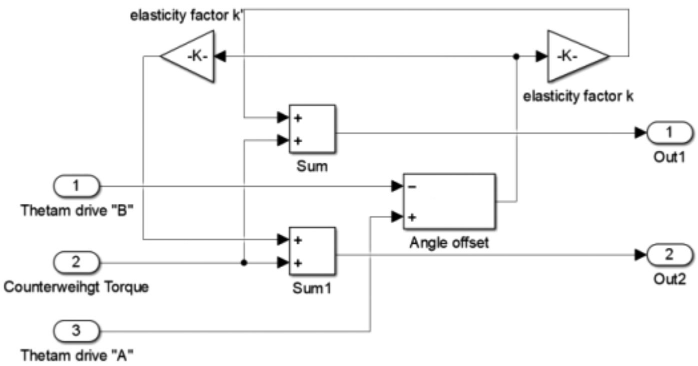


Fig. 7. The subsystem model representing the mutual impact of the drive systems

Fig. 8 shows the velocity of the cabin door obtained by computer simulation, assuming the use of one and two motors in the proposed control topology.

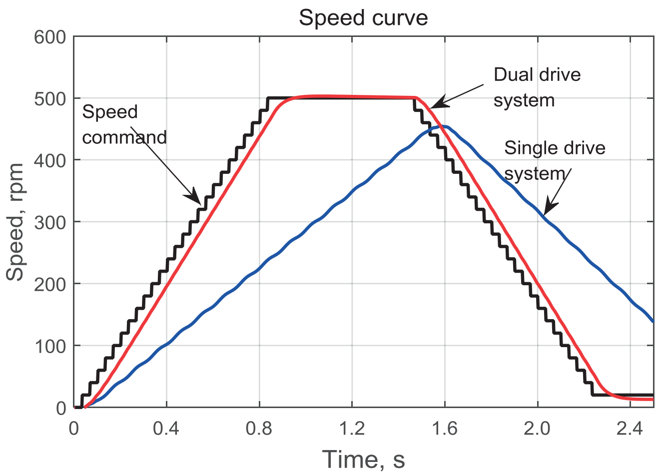


Fig. 8. Set speed and actual speed for one and two drive motors

It is clear that for a heavy door a single drive system is not capable of providing the right operating parameters. The use of an additional drive system allows the device to function properly.

7. The influence of data transmission delay on the operation of the drive system

The setpoint of the I_q component and the current regulator developed by the Master controller regulator must be sent to the Slave controller. This process is carried out using a serial bus. The transmission is always charged with a time delay, which is inversely proportional to the nominal data transfer rate and directly proportional to the length of the data frame.

In the case of high-speed controller area network (CAN) industrial buses operating at speeds of the order of 1 Mbit/s, the transmission and handling of a standard data frame with an 11-bit identifier by the receiving system usually takes about 100 μs when transmitting 4 bytes of data.

The waveforms generated during the simulation clearly show the oscillation of the moment, which results from the inaccurate operation of the controller's torque regulator system "Slave". It can be suspected that such a drive system could emit acoustic disturbances difficult to accept by users during operation.

The following Fig. 9 shows the courses obtained by computer simulation, made for the same belt tension, and various transmission delay times between the Master controller and the Slave controller.

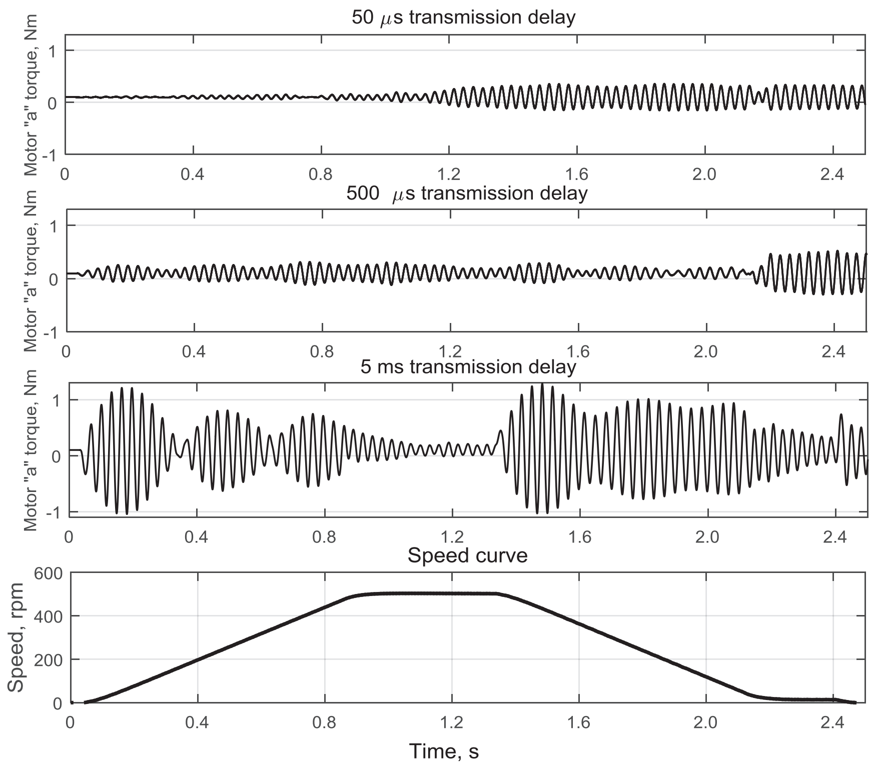


Fig. 9. The course of speed and torque on the shaft of one of the motors of the proposed control system as a function of the data transmission delay time

A strong influence of this parameter on the operation of the propulsion system is clearly visible.

In practice, the transmission speed rarely reaches the assumed value of 1 Mbit/s, which further affects the operation of the propulsion system and significantly hinders its construction.

Excessive torque fluctuations on the shaft of the motors could also lead to premature wear of the transmission belt and drive wheels. An interesting phenomenon is that the frequency and amplitude of oscillations strongly depend on the belt tension and such a drive system would change its operating parameters in a wide range during its operation.

Despite the occurrence in such a system of torque oscillation on the motor shafts, it fulfills its task of controlling the cabin doors, proving sufficient for their work.

8. Propagation time compensation

In order for the adjustment process to take place correctly, it should take into account the delay introduced by the process of transmitting data on the control parameters from the Master controller to the Slave. To compensate for the time delay that the data transfer process introduces to the control loop, a new setpoint value of the I_q component of the stator current in the Master controller should be entered with a delay equal to the frame propagation time with the data between the controllers. This delay causes new parameters of the motors to be fed in at the same moment of time, which does not interfere with the operation of speed and torque regulators. The need to accurately shape the driving curve of the cabin door requires that the data about the setpoint of the I_q component of the current should be transmitted as quickly as possible to prevent the delay introduced by the transmission system from significantly affecting the adjustment process.

According to these assumptions, the model of the control system was modified by introducing an additional delay block between the torque regulator and the vector modulator of the Master controller converter (Fig. 10).

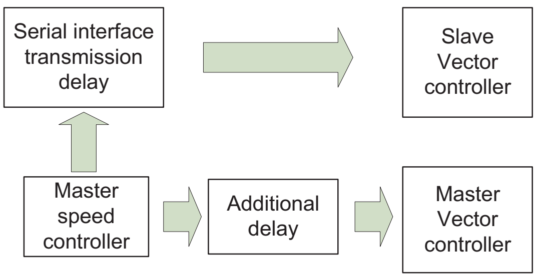


Fig. 10. Data flow diagram for the developed drive system

If the delay time of changes in the controller of the Master controller is identical with the time of propagation of information to the Slave controller, then with a small approximation (single microseconds) we can assume that both propulsion systems will modify the value of the given I_q component in a similar time, which should result in a comparable course of the torque produced by the machines as a function of time.

According to these assumptions, it is important both to achieve very short propagation times and to minimise the offset of the system introducing the controller of the setpoint torque by both drive systems.

A simulation of the system's operation was performed for different information transmission speeds. Since it is not possible to make changes at the same time, the minimum time difference between the drive systems is equal to the period of control of the transistors and is 50 μs for our case (Fig. 11).

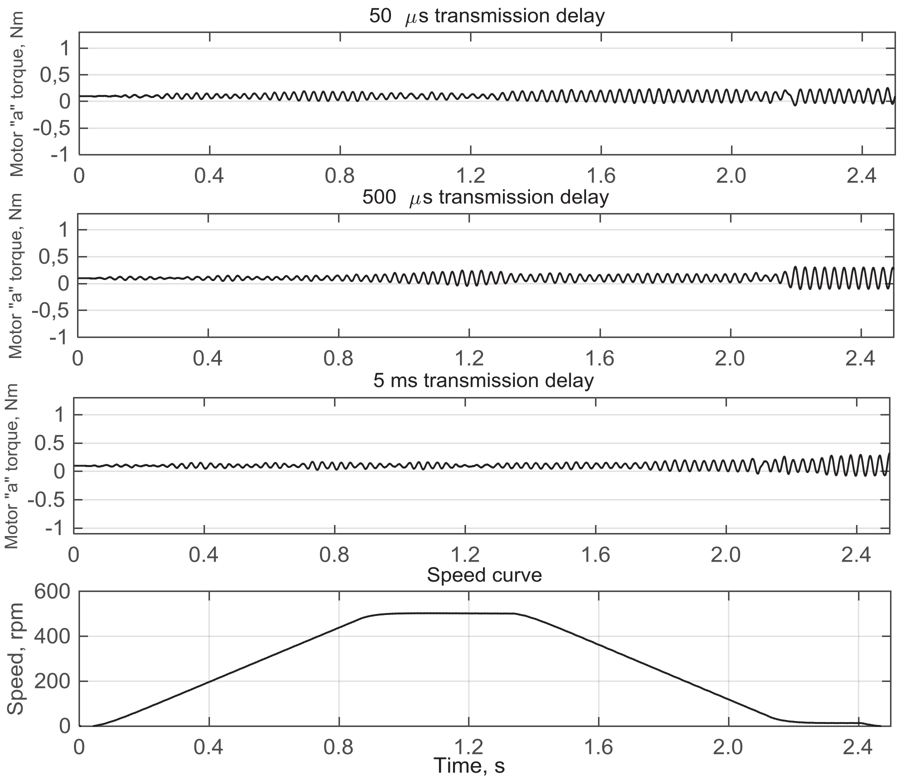


Fig. 11. The course of speed and torque on the shaft of one of the motors of the proposed control system using an additional delay block

With the parameter of the information transmission delay assumed in this way, torque ripples on the shafts of individual drive motors are noticeable; this, however, does not negatively affect the total drive torque. It can also be seen that their amplitude does not change in a wide range as a function of the increasing information transmission time.

The conducted simulations show that the proposed control system works properly in a wide range of possible propagation times, and oscillations of torque on the shafts of individual motors, assuming the minimisation of the information transmission time, should not have a significant impact on the operation of the propulsion system.

9. The influence of the regulator gain factors on the torque oscillations on the drive motor shaft

It is advisable to determine the influence of changes in the gain factor of the driver speed regulator loop on the operation of such a drive system. It can be assumed that this influence is significant both for determined operating conditions and for dynamic states during acceleration or braking of a drive system consisting of two concurrently operating drives in the Master-Slave system. Simulation of the operation of such a system was performed for different proportional gain coefficients and the integration factor of the integrator. Simulations were carried out for the same tension of the transmission belt. The results are shown in Figs. 12 and 13.

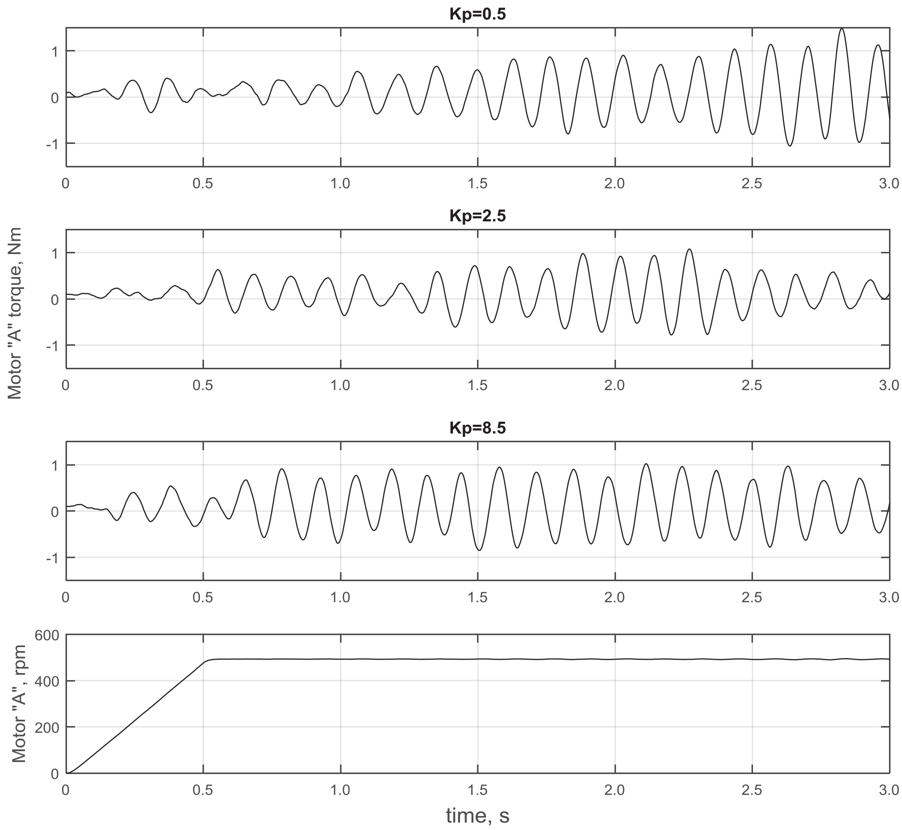


Fig. 12. The torque course on the motor shaft "a" for different proportional gain factors

It can be noticed that changes in the gain coefficients of the proportional and integral element do not affect the amplitude of the torque changes on the motor shaft "a" too much. This is very important information as it indicates that changes in these factors should not cause negative consequences. Interestingly, the amplitude of the torque changes on the motor shaft seems to be slightly smaller for the larger values of the integral component of the gain factor.

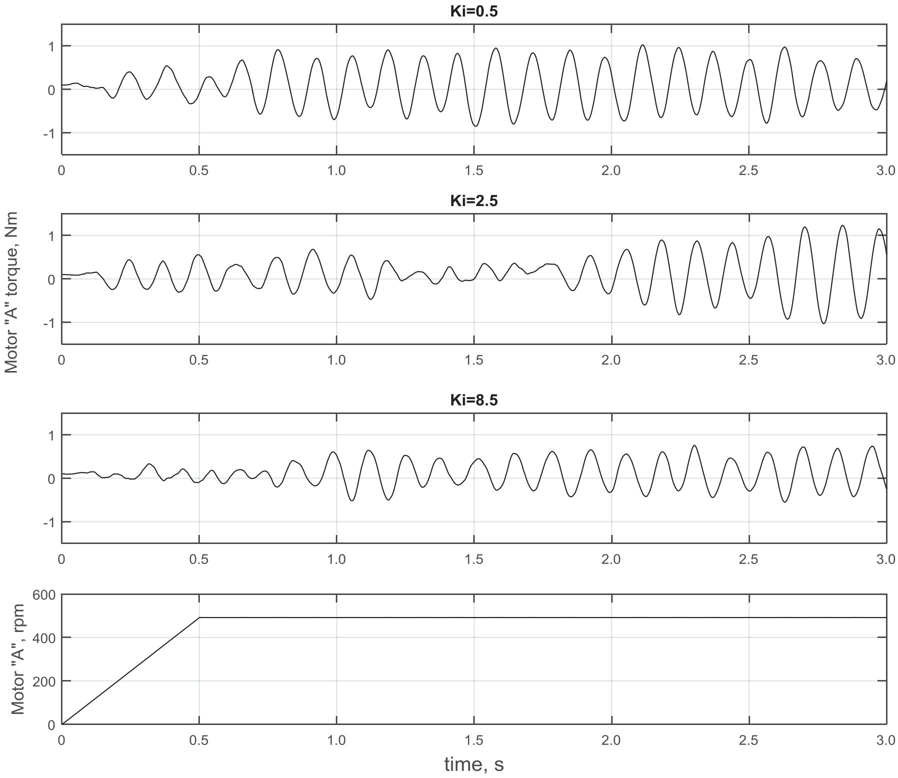


Fig. 13. The torque course of the motor shaft "a" for different integrating factors of the integrator

10. The influence of the transmission belt tension on the operation of the drive system

The flexible coupling of two drive systems is a combination whose properties are not constant over time. Both the initial tension of the belt and its change under the influence of forces active during operation of such a device cause that the conditions of cooperation between the two propulsion systems are constantly changing, and despite satisfactory results at the beginning of such a system, the end result considered in the long term may be unsatisfactory.

It seems advisable to carry out simulation studies of the operation of such a drive system for various belt drive strokes and comparative analysis of the correct operation of the device in static and dynamic states (Fig. 14).

On the basis of simulations, we can conclude that apart from the amplitude of the torque oscillations on the shaft of the drive motor, their frequency also changes. It is clearly visible that with a greater belt tensioning force these values are larger and should decrease during the operation of the device. This indicates that the worst working conditions for such a drive system exist shortly after it is started – when the belt tension is greatest. If the parameters of the work

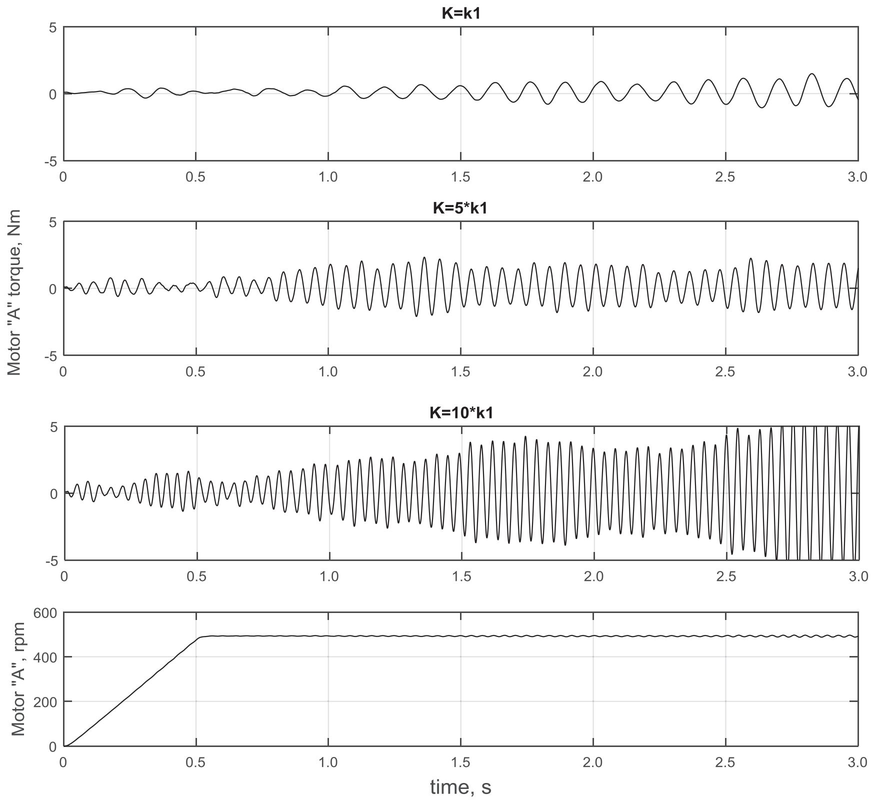


Fig. 14. The course of the torque on the motor shaft "a" for various tensions of the transmission belt

are satisfactory right after the installation, it should be assumed that they will not deteriorate in the course of subsequent operation. This assumption justifies the use of advanced adaptive speed controllers whose parameters could change during operation in accordance with the rules developed e.g. by algorithms based on neural networks [10].

11. Design assumptions

The developed drive system is equipped with two serial interfaces that can act as a logical connection between controllers. The standard interface is an RS-232 compatible line that can transmit data at 115 Kbps. The second serial link is the modern CAN bus in the 2.0 A specification, by means of which data can be transmitted at speeds of up to 1 Mbit/s. Since the CAN bus is used to communicate with the main controller of the lift, it was decided to use the RS-232 data transmission link. The data range for transmission is defined as a 16-bit character variable, which makes the transmission time of this value around 180 μs and with such delay the Master controller's regulator introduces new control parameters. The use of a CAN bus would reduce the delay to about 30 μs, but at the same time a large number of data frames would be generated on the lift control bus, which could cause incorrect operation of the lift's own control system as well as input/output systems (call and command buttons, and floor indicators) using a common system control bus (Fig. 15).

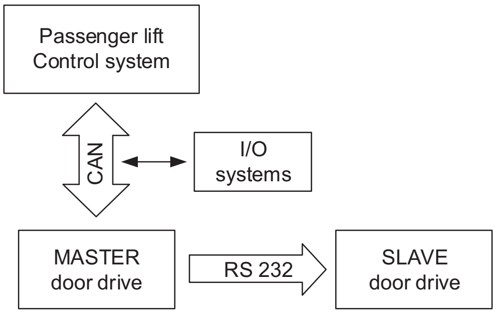


Fig. 15. Block diagram of information flow in a dispersed personal crane structure with a developed drive system

Due to the fact that the speed controller actually controls two motors, its gain factors should be reduced approximately twice. This should positively affect the value of speed regulation of the propulsion system of passenger lift cabin doors. At the same time, the parameter determining the maximum force acting on the passenger when closing the door should be reduced by half due to the presence of a second drive producing a compliant torque.

12. Research on a real object

To test the efficiency of the drive system consisting of two PMSM motors working on the "common shaft", a stand was prepared consisting of cabin doors coupled with shaft doors with a common mass of 380 kg, being a standard market product, and two drives with synchronous 150 W motors with rated speed of 500 rpm equipped with incremental encoders – a prototype solution for the cabin door drive system (Fig. 16).

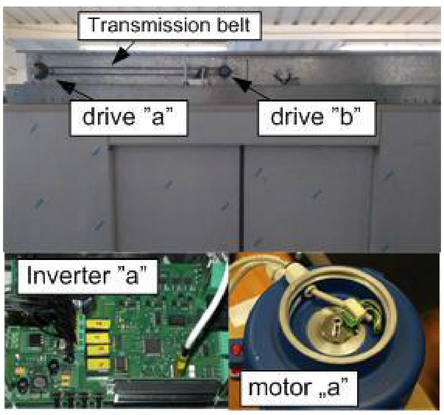


Fig. 16. Testing stand with real door "dual" drive system

System software has been developed in which the drive operation mode is determined by means of a parameter in the electrically erasable programmable read-only memory (EEPROM), which can be modified from the service menu level (so as to avoid misuse by inexperienced users). After connecting two independent drives with PMSM motors via a serial bus, they begin concurrent work consistent with the assumption of the follow-up drive [4]. On the real model, the actual speed course was recorded for single-drive operation and the operation of a propulsion system consisting of two inverters and two motors operating in the described relation (Fig. 17).

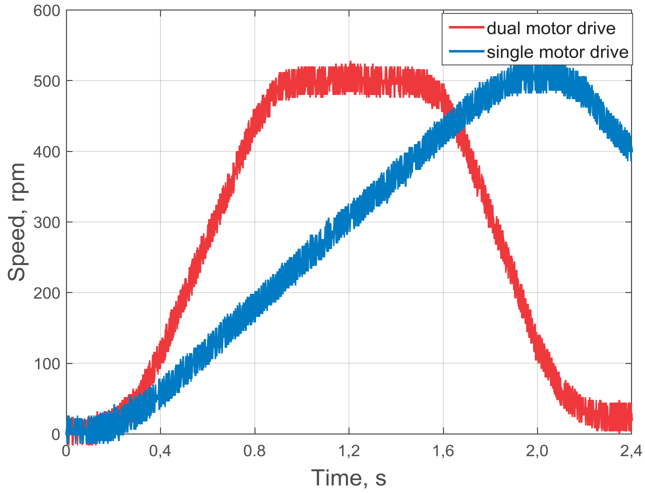


Fig. 17. The speed course of the door using one and two coupled drive systems

It can be noticed on the waveforms that if a one-drive motor is used, its torque is insufficient to achieve the desired parameters of the dynamics and speed of the cabin doors. The connection of the second drive and its proper configuration significantly improves the operating parameters. At the same time oscillations of the drive torque do not negatively affect the operational comfort of the devices in the entire useful range of the belt tension.

13. Conclusions

The developed control system for the passenger lift cabin door drive has met the design assumptions. In the case of heavy doors, the use of an additional drive system means that the assumed speed and its trajectory are achieved, and thus the efficiency of the lift (the number of possible rides) is at the assumed level. At the same time, the use of typical smaller-door drives and the lack of the need to modify the mechanical design of the door makes the economic feasibility of such a solution, although it uses two independent drive systems, is much higher than a dedicated solution with one motor and modified mechanical construction. At the same time, the cost of any repairs and their duration due to the use of standard solutions will be considerably reduced, which will significantly affect the perception of the device by consumers and service on a long-term basis. In the proposed control topology it is not possible to fully synchronise the torque controllers of both drives. This results in the occurrence of torque oscillations on the motor shaft, which in extreme cases lead to improper operation of the entire system. Similar regulation principles apply to less advanced systems using non-vector control methods for permanent magnet motors. Attempts have been made to implement the described experiments in controlling drive systems with sinusoidally controlled BLDC motors. This method is a simplified method in relation to vector control of the PMSM engine, but it has similar features in terms of positioning capabilities of the motor shaft position with a much reduced phase current measurement system and a simplified algorithm for shaping the stator flux vector. The tests also showed a better quality of the so-controlled drive system using an additional block compensating for the delay in the introduction of new parameters for the Master and Slave drive torque controllers.

It has been shown that after using an additional delay block, a significant reduction in the amplitude of oscillations is possible, which allows the use of such topology in industrial practice.

The discussed solution has been tested and implemented for series production of heavy cabin doors used in car transport equipment in car parks equipped with car lifts.

References

[1] Kolano K., *Lift car doors drive system with hi-efficient BLDC drive*, Przegląd Elektrotechniczny (in Polish), no. 11b, p. 348 (2012).

[2] Dziubiński M., *Failure prediction and simulation of the starting system*, Second International Conference on Reliability Systems Engineering (ICRSE), pp. 1–6 (2017).

[3] Kolano K., *Lift door follow-up drive system with a PMSM motor*, 2017 International Symposium on Electrical Machines, SME 2017, Naleczow, Poland (2017).

[4] Nalepa R., Orłowska-Kowalska T., Szabat K., *Assessment of PMSM torque linearity for advanced tuning of high performance electric drives*, 14th Internat. Power Electronics and Motion Control Conference (EPE/PEMC), pp. T5-126–T5-129 (2010), DOI: 10.1109/EPEPEMC.2010.5606506.

[5] Sichen Fang, Bo Zhou, Ying Liu, *Design and realization of dual redundancy PMSM electrical drive systems*, 4th IEEE Conference on Industrial Electronics and Applications, ICIEA 2009, pp. 1985-1989 (2009), DOI: 10.1109/ICIEA.2009.5138550.

[6] Zhenqiang Yang, Jialu Du, Shuanghe Yu, Shuang Liu, *DSP-based design and implementation of a smart elevator door motor control system*, 8th Asian Control Conference (ASCC), pp. 235–238 (2011).

[7] Hyunchal Oh, Ki Young Song, Kwan Yuhl Cho, Hag Wone Kim, Byung Moon Han, *Initial rotor position detecting algorithm of PM synchronous motor using incremental encoder*, IEEE ECCE Asia Downunder, pp. 681–686 (2013), DOI: 10.1109/ECCE-Asia.2013.6579174.

[8] Marufuzzaman M., Reaz M.B.I., Rahman M.S., Ali M.A.M., *Hardware prototyping of an intelligent current dq PI controller for FOC PMSM drive*, 2010 Internat. Conference on Electrical and Computer Engineering (ICECE), pp. 86–88 (2010), DOI: 10.1109/ICELCE.2010.5700559.

[9] Sorgdrager A.J., Grobler A.J., *Influence of magnet size and rotor topology on the air-gap flux density of a radial flux PMSM*, IEEE International Conference on Industrial Technology (ICIT), pp. 337–343 (2013), DOI: 10.1109/ICIT.2013.6505695.

[10] Zawirski K., Pajchrowski T., *Adaptive neural speed controller for PMSM servodrive with variable parameters*, 2012 15th Internat. Power Electronics and Motion Control Conference (EPE/PEMC), Novi Sad, pp. LS6b.3–1-LS6b.3–5 (2012), DOI: 10.1109/EPEPEMC.2012.6397491.