ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2007. No. 5(77)
ELEKTRONIKA IR ELEKTROTECHNIKA

AUTOMATION, ROBOTICS
T125
AUTOMATIZAVIMAS, ROBOTECHNIKA

Investigation of Velocity Control System with Programmable Variable Structure Controller

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Introduction

The dynamical quality improvement technique of the velocity control system has been proposed and analyzed in the articles [1, 2]. The core of this technique is the variable structure velocity controller application. The control law of such a velocity controller can be changed automatically from the proportional integrating (*PI*) mode to the proportional (*P*) mode and vice versa during the transient regime of the servo drive. The following algorithm of the controller control law change has been proposed and investigated [2]: in the initial phase of the transient regime of the drive the velocity controller is adjusted according to the *PI* control law corresponding to the symmetric optimum condition; at the time when the armature current reaches its maximum value, the control law is switched to the *P* control law corresponding to the quantitative optimum condition; finally, after some delay time the control law is switched again from the *P* to the *PI* mode and remains unchanged up to the end of the cycle. This delay time depends on the load of the drive and is to be defined on line during the transient regime. The Fuzzy logic control approach for the delay time definition has been proposed and the velocity control system with a variable structure controller commanded by a special Fuzzy logic based delay time definition device has been investigated in the article [3]. The Fuzzy logic device is used for the *P* control law interval time definition in dependence on the static load level of the system and allows ensuring optimal dynamical quality of the velocity control system. Two types (Mamdani-type and Sugeno-type) Fuzzy logic *P* control law interval time definition devices have been designed and investigated [3].

Another *P* control law interval time definition method is proposed in this article. This method is based on the previously programmed "Lookup Table" application for the *P* control law interval time definition in the velocity control system.

The problem arises with the static load level definition as input signal of the programmable device during transient regime. Therefore the Luenberger observer is designed for the static load current estimation and is presented in this paper.

Discussion of velocity control system with programmable velocity controller

The block diagram of the DC electric drive velocity control system with variable structure controller, commanded by the programmable delay time definition device, is presented in Fig. 1. The velocity control system consists of the internal motor current control system, represented by the simplified transfer function

$$H_{CL}(s) = \frac{k_{CL}}{2T_c s + 1}, \quad (1)$$

the mechanical part of the system with transfer function

$$H_M(s) = \frac{k_M}{s}, \quad (2)$$

a velocity feedback k_Ω, the Luenberger observer *LO* (applied for the static load current estimation) and the programmable variable structure velocity controller *PVSC*. The main parts of the *PVSC* are the variable structure controller itself *VSC*, able to turn proportional (*P*) control law

$$H_P(s) = k_{P\Omega}, \quad (3)$$

to proportional-integrating (*PI*) control law

$$H_{PI}(s) = k_{P\Omega}(1 + \frac{1}{8T_c s}), \quad (4)$$

and vice versa, the control law switching block *SB*, and the programmable delay time definition device *PTD.* There in the expressions (1,2,3,4) the following definitions are applied: $k_{P\Omega}$ denotes a gain of the proportional (*P*) velocity controller, k_{CL} - a gain of the closed current control loop, k_M - a gain of the mechanical part, T_c - a small time constant of the power converter of the electric drive.

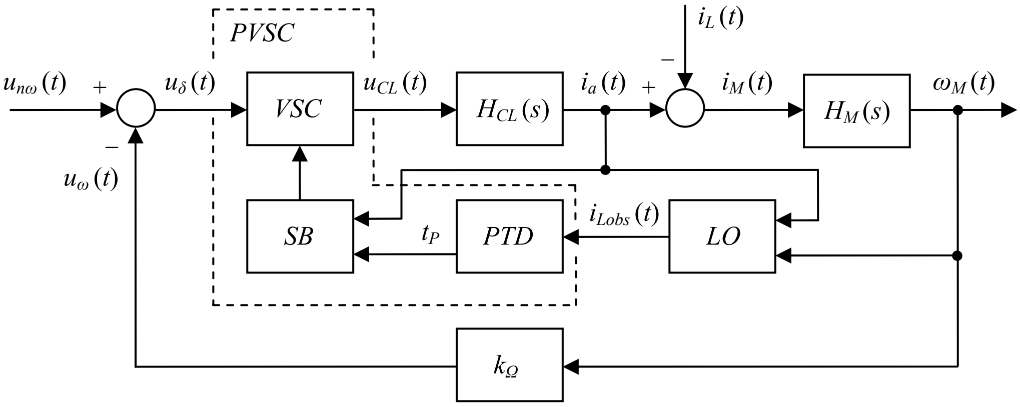


Fig. 1. Block diagram of the velocity control system with programmable variable structure velocity controller *PVSC* and Luenberger observer *LO*

On the base of the results obtained in [2], the following control algorithm of the velocity controller control law change is defined: in order to obtain the extreme rapidity of the transient regime in the start phase of the drive (after applying the control signal $u_{n\omega}$), the velocity controller switches according to the *PI* control law. Owing to this, the acceleration of the motor is forced. At the time when the motor armature current reaches its maximum value $i_{a\max}$, velocity controller is turned to the *P* control law (the integrating channel is disconnected and discharged). After some delay time defined by the programmable delay time definition device *PTD*, the velocity controller control law is returned again to the *PI* control law (for the steady-state velocity error elimination) and remains unchanged up to the new start of the drive.

Design of Luenberger observer

An observer is a device (mathematical structure) for the state-variables or parameters of the control system estimation [4, 5]. The observers are applied when direct measurement of the system parameters is complicated or even impossible. The static load torque (load current) of the velocity control system just distinguishes by such features.

In order to estimate the static load current, the Luenberger observer has been constructed (Fig. 2).

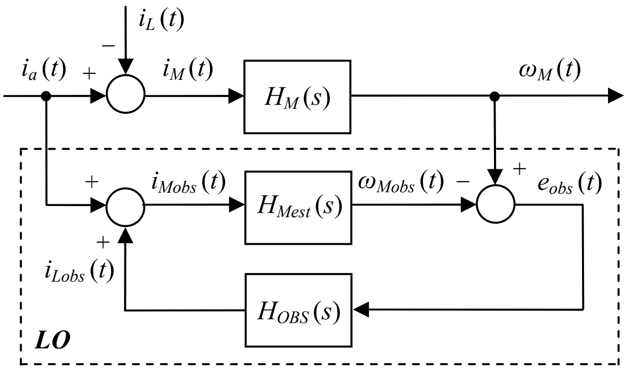


Fig. 2. Structure of the Luenberger observer *LO*

The armature current i_a acts as a command signal in the feed forward (prediction) path of the observer. H_{Mest} is an exact replica of the mechanical part of the velocity control system - H_M. The observer error e_{obs} is formed from the difference of the actual motor velocity ω_M and the observed motor velocity ω_{Mobs}. The observer compensator (used for the observer error reduction) with transfer function

$$H_{OBS}(s) = k_{OBS} \tag{5}$$

operates in the feedback (correction) path of the observer (Fig. 2). In (5) equation: k_{OBS} - a gain of the observer compensator.

In Fig. 3 are presented two nominal static load current curves of the transient regime. The curve named *Act* is the actual nominal static load current and the curve named *Obs* is the observed nominal static load current. It is demonstrated in Fig. 3, that the value of the observed nominal static load current asymptotically converges to the value of the actual nominal static load current. It is obvious from Fig. 3, that the convergence time is shorter than the *PI-P* control law switching time (denoted by a vertical *ST* line). The increase of the gain value of the observer compensator decreases the convergence time. The nominal static load current curves of the transient regime (Fig. 3) are obtained when the gain value of the observer compensator is set to k_{OBS}=3.

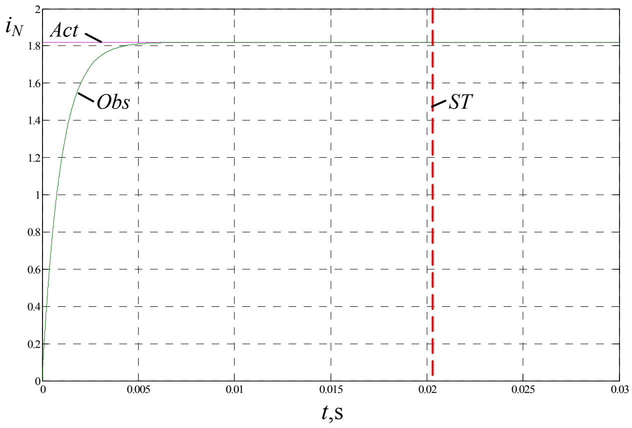


Fig. 3. Nominal static load current $i_N(t)$ curves of the transient regime

It is achieved that the observed static load current obtains steady-state value (equal to the actual value) before control law change from *PI* to *P* mode is occurred (Fig. 3), thus it is suitable to pass this derived static load current signal from the Luenberger observer to the *P* control law delay time definition device.

Design of programmable delay time definition device

Initially some tests [2] have been repeated in order to correct and supplement the input-output dependence of the delay time definition device - the t_P=f(I_R)=f(I_L/I_N) diagram [3] (represented in Fig. 4), where t_P - the duration time of the proportional (*P*) control law, I_L - the settled load current value, I_N - the nominal load current value, I_R - the relative load current value (ratio of I_L and I_N currents).

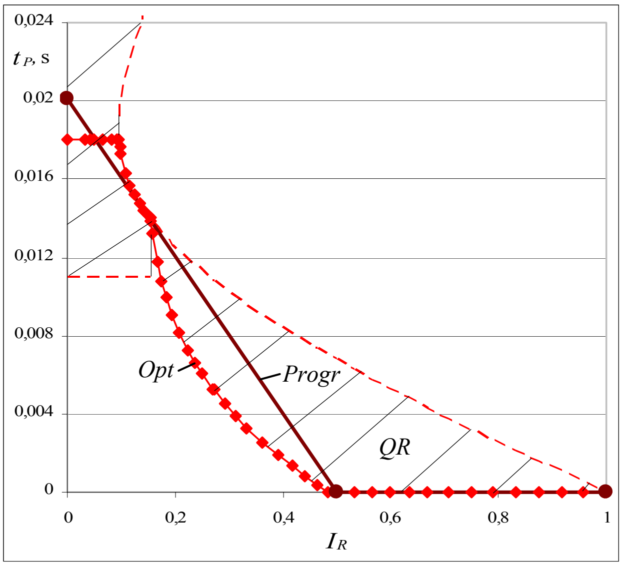


Fig. 4. t_P=f(I_R)=f(I_L/I_N) diagram: input-output dependence of the programmable delay time definition device

The *Opt* curve (Fig. 4) has been corrected by series of tests [2] and demonstrates optimal t_P=f(I_R) dependence. The SISO (single input - single output) delay time definition device with implemented optimal t_P=f(I_R) dependence ensures the best dynamical quality (defined by the *ITAE* quality criterion [2]) of the velocity control system. The deviation of the duration time (t_P) from the optimal values (*Opt* curve) causes the decline of the dynamical quality of the velocity control system. The quality region *QR* of the duration time (t_P) change is defined (Fig. 4, lined zone). Within the *QR* the dynamical quality of the velocity control system decreases up to 5% compared to the best dynamical quality. Nevertheless this possible decrease of the dynamical quality due to the duration time (t_P) change is considered as acceptable.

The programmable SISO delay time definition device *PTD* is built in the form of the "Lookup Table": the input variable - the load current value (obtained from the Luenberger observer) is mapped to the corresponding output variable - the duration time of the proportional (*P*) control law. Considering the defined quality region *QR* the input-output dependence of the programmable device - t_P=f(I_R)=f(I_L/I_N) curve (named *Progr* in Fig. 4) is developed and is described by two linear functions:

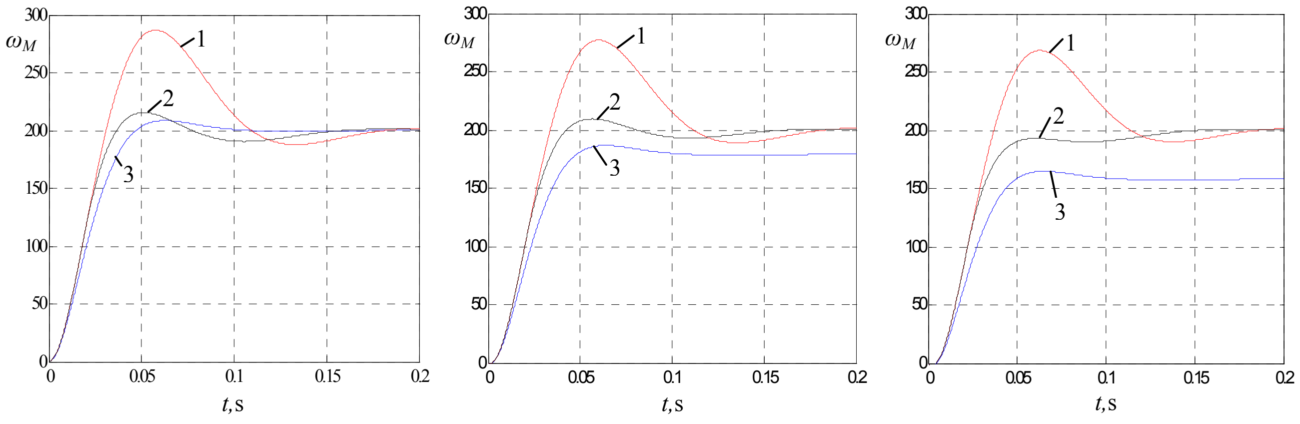
$$Progr = \begin{cases} 0.0201 - 0.0402 \cdot I_R \text{, when } 0 \le I_R < 0.5, \\ 0.00001 \text{, when } 0.5 \le I_R \le 1. \end{cases} \qquad (6)$$

The developed *Progr* curve is located within the quality region *QR* (Fig. 4) and coincides with *Opt* curve in the range [0.5÷1] of the I_R (thus, the best dynamical quality of the velocity control system is achieved), but differ a little from *Opt* curve in the range [0÷0.5) of the I_R (thus, the dynamical quality declines up to 5% compared to the best dynamical quality of the velocity control system). Consequently the developed input-output dependence (*Progr* curve) is suitable for implementing in the programmable SISO delay time definition device.

Simulation results of velocity control system

The simulation has been performed using MATLAB/ Simulink package. It was used the fifth-order Dormand-Prince numerical integration method with fixed step size 0.00001. It was applied the unit step control signal $u_{n\omega}(t)=1(t)$.

The velocity transient regime curves obtained using variable and conventional structure velocity controllers are presented in Fig. 5. There the curves obtained using velocity controller adjusted under the symmetric optimum condition are denoted by number 1, in the case of using programmable variable structure velocity controller *PVSC* (with the implemented input-output dependence – the developed *Progr* curve (Fig. 4)) – by number 2, and in the case of using velocity controller adjusted under the quantitative optimum condition – by number 3.



a b c

Fig. 5. Velocity curves of the transient regime: a - in the idle case, b - in the static load I_L=0.5I_N case, c - in the static load I_L=1I_N case

It is seen from the Fig. 5, that in all cases, the rapidity of the velocity control system with *PVSC* has been increased comparing to the drives with conventional structure velocity controllers. Hence the dynamical quality of the velocity control system has been improved using *PVSC*. Furthermore the velocity transient regime curves obtained using programmable variable structure velocity controller *PVSC* are identical to the velocity transient regime curves obtained using Fuzzy logic based variable structure velocity controller [3], consequently both *P* control law interval time definition devices (Programmable and Fuzzy logic based) are suitable for implementing the proposed dynamical quality improvement technique.

Conclusions

1. The velocity control system with programmable variable structure velocity controller is developed and investigated. The programmable device defines *P* control law interval time in dependence on the static load level of the system.

2. The static load current estimation is performed by the designed Luenberger observer. The derived static load current signal is suitable for use in the *P* control law interval time definition device.

3. Considering the defined quality region *QR* of the duration time (t_P) change the input-output dependence of the programmable device ensuring optimal dynamical quality of the velocity control system independently on the static load conditions is developed. The presented simulation results of the velocity control system using programmable variable structure controller coincide with analogical results obtained applying Fuzzy logic based variable structure controller [3]. Thus both *P* control law interval time definition devices are suitable for the implementation of the proposed dynamical quality improvement technique.

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Submitted for publication 2007 03 01

N. Šulčius, V. A. Geleževičius. Investigation of Velocity Control System with Programmable Variable Structure Controller // Electronics and Electrical Engineering. – Kaunas: Technologija, 2007. – No. 5(77). – P. 53–56.

The velocity control system with programmable variable structure velocity controller is developed and investigated. The programmable device defines *P* control law interval time in dependence on the static load level of the system. The static load current estimation is performed by the designed Luenberger observer. The derived static load current signal is suitable for use in the *P* control law interval time definition device. The input-output dependence of the programmable device is developed ensuring optimal dynamical quality of the velocity control system independently on the static load conditions. The presented simulations results of the velocity control system using programmable variable structure controller coincide with analogical results obtained applying Fuzzy logic based variable structure controller. Ill. 5, bibl. 5 (in English; summaries in English, Russian and Lithuanian).

Н. Шульчюс, В. А. Гяляжявичюс. Исследование системы управления скорости с программируемым регулятором переменной структуры // Электроника и электротехника. – Каунас: Технология, 2007. – № 5(77). – С. 53–56.

Рассмотрена система управления скорости с программируемым регулятором скорости переменной структуры. Программируемое устройство использовано для определения длительности пропорционального (*П*) закона управления в зависимости от статической нагрузки системы. Оценка тока статической нагрузки выпольнена с примененныем наблюдателя Луенбергера. Полученный сигнал тока нагрузки можно использовать в устройстве определения длительности *П* закона управления. Вход-выход зависимость программируещего устройства подобрана так, чтобы было обеспечено оптимальное качество динамики системы независимо от статической нагрузки. Результаты моделирования системы управления скорости с программируемым регулятором переменной структуры совпадают с результатами, полученными с применением метода *Fuzzy* логики. Ил. 5, библ. 5 (на английском языке; резюме на английском, русском и литовском яз.).

N. Šulčius, V. A. Geleževičius. Greičio valdymo sistemos su programuojamuoju kintamos struktūros reguliatoriumi tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007. – Nr. 5(77). – P. 53–56.

Nagrinėjama greičio valdymo sistema su programuojamuoju kintamos struktūros greičio reguliatoriumi. Programuojamasis įtaisas naudojamas proporcinio (*P*) valdymo dėsnio palaikymo trukmei nustatyti priklausomai nuo sistemos statinės apkrovos dydžio. Statinės apkrovos srovei nustatyti sudarytas *Luenbergerio* observatorius. Gaunamas statinės apkrovos srovės signalas yra tinkamas naudoti *P* valdymo dėsnio palaikymo trukmės nustatymo įtaise. Sudaryta programuojamojo įtaiso įėjimo ir išėjimo priklausomybė užtikrina optimalią sistemos dinamikos kokybę nepriklausomai nuo statinės apkrovos dydžio. Pateikti greičio valdymo sistemos su programuojamuoju kintamos struktūros reguliatoriumi modeliavimo rezultatai sutampa su rezultatais, gautais taikant *Fuzzy* logika pagrįstą kintamos struktūros reguliatorių. Il.5, bibl. 5 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).