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Analysis and Intelligent Control of Heavy Duty Vehicle Software Architecture Components

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ABSTRACT

The defense industry is rapidly growing in our country. The domestic and national designs of heavy duty vehicles are standardized by many application software programs which are used to model and analyze the plant model and control model. This paper focuses on the modeling of the transmission components of heavy duty vehicles used in the defense industry and the different techniques to standardize them. The paper first introduces the component which is used in heavy duty vehicle transmission modeling. Second, this paper focuses on the modeled PID controller to control the plant model. Third, the conventional controller is defined. Fourth, the analysis of two different controllers and the outputs of this heavy duty component are explained. The requirements for future work are also defined in this paper.
Index Terms—Automated manual transmission component, defense industry, heavy duty vehicles

I. INTRODUCTION

Considering the world's economy from a broad perspective, its location and importance are striking [1]. During the Cold War, expenditure on research and development in the defense industry was high, the products were long-lived, and the market was wide. However, the industry was riddled with technical uncertainties [2]. World politics was changed by incidents of terrorism that manifested around the world with the end of the war. Due to the divisions created and the conflicts in international politics, the defense industry has witnessed an acceleration in its growth and development.

The growth of the defense industry in our country is extremely rapid. There have been many studies of the defense industry in Turkey [3]. Tülay Baran, in her paper, investigates the defense industry in Turkey and evaluates the effects of defense industry spending on the economy [3]. She claims that before 1980, defense services in Turkey, which were public goods, depended on foreign sources. However, since 1980, there has been a gradual shift away from dependence on foreign sources. Moreover, Balcı [1] demonstrates the importance of the defense industry's collaborative work with the university, and states the significance of university–industry collaborations, especially in terms of the defense industry, as a fact. Both the determination of university needs and the advocacy of a technology transfer that can significantly contribute to the development of the industry with national objectives in mind, are a part of the way forward.

There are a large number of projects to manufacture heavy duty vehicles for the Turkish military defense industry, such as the ARMA Armored Combat Vehicle, the ALTAY National Tank, the KİRPİ- COBRA Armored Wheeled Vehicle, the PARS Armored Combat Vehicle, etc. Most of them have 100% percent Turkish engineering designs. The investment made in the Turkish defense industry will result in the fact that all heavy duty military vehicles are based entirely on domestic engineering designs in the near future. The aim of this study is to present a different perspective to the application software and control of the automated manual transmission (AMT) system to be used by a heavy duty vehicle designed for a defense industry, which is one of the different transmission systems used in heavy duty vehicles [4]. The defense industry requires mobility solutions that can operate in extreme conditions, are capable of performing a variety of specialized tasks consistently, and can withstand the abuse and challenges they face during operations [4]. As in all facets of the mobility industry, electrification is redefining what is possible in the

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world of defense. Electrified powertrains, large on-board modular energy storage systems, and options for high voltage generation by either fuel cell systems or diesel electric generators are now available and offer significant potential.

Especially in heavy duty vehicles, there are many application software programs which are used in order to model and analyze the plant model and control model to control the domestic and national designs. Moreover, this paper focuses on the modeling of the heavy duty vehicle's transmission component that is being used in the defense industry and its different control techniques. First, this paper introduces the component which is used in heavy duty vehicle transmission modeling. Secondly, this paper focuses on the modeled PID controller to control this plant. Thirdly, the conventional controller is defined. Fourthly, the two different controllers and the outputs of this heavy duty component are explained and analyzed. In this paper, the MATLAB Simulink tool is used in order to identify and control the mathematical expressions of the plant model. As mentioned in the Conclusion section, the advantages of anti-windup techniques are implemented. Moreover, the goals of future work are also defined in this paper.

II. PLANT MODEL

Different transmission types have many different transmission component topologies. This paper focuses on an AMT-type transmission component, a valve and a solenoid. For the AMT-type transmission valve, the solenoid plant model is very important. There are two main types of valves (on-off and proportional) which follow the solenoids' working principle directly, in order to decide how much it should open and close. Further, if the valve works as an on-off valve, depending on the requirements of the project, there is no major specification requirement regarding sensitivity of the transmission system. For some of the heavy duty transmission types, sensitivity on driving has no priority-one request. Because the expected situation in a heavy duty vehicle is high performance of the system rather than the driving sensitivity, unlike passenger vehicles in which the driving comfort is more important, the expected conditions in a heavy duty vehicle are not valid. On the other hand, there are some advantages of using a proportional valve, the most important being that the proportional valve can be controlled. Controlling the valve is very important whenever high performance control is needed, especially for current-controlled electro-hydraulic valves.

The valve model behaves as a proportional valve, that is, the valve controls the hydraulic oil pressure proportionally by means of current. Fig. 1 shows the proportional valve model. Therefore, this plant model behaves as a current-controlled hydraulic oil pressure for AMT for heavy duty vehicles in the defense military system. Fig. 2 shows the solenoid model. The solenoid model receives current-controlled hydraulic oil pressure and this pressure allows the solenoid to arrange stroke length. The mathematical expressions for the valve plant model can be summarized with the expressions shown below. Current can be determined by voltage via the transfer function. Moreover, this current value is normalized with the maximum current that the valve can work with. By considering the offset values of valves and dead-zone scaling factors, we arrived at the proportional valve data. By multiplying the proportional valve data with instant hydraulic oil pressure, the current-controlled hydraulic oil pressure value is determined.

$$I_{norm} = I_{valve} / I_{maxvalve} \quad (1)$$

$$I_{effectedcurrent} = I_{norm} - I_{offset} \quad (2)$$

$$I_{propvalve} = I_{effectedcurrent} \text{ [scaling process]} \quad (3)$$

The mathematical expressions of the solenoid plant model can be summarized with the expressions shown below. The current-controlled hydraulic oil pressure value in bar is converted to Pascal (Pa) with bar-to-Pascal scaling. As described in Chapter 2.1, after determining the force, the frictional force should be considered in order to get the net force of stroke movement. After obtaining to net force of stroke movement, the acceleration, velocity, and displacement of the stroke are determined by taking the integration of each of them in order to define solenoid characteristics with mathematical expressions.

$$Hoil_bar \times 10^5 = Hoil_Pa \quad (4)$$

$$F = P \times A \quad (5)$$

$$F_{net} = F - Friction \quad (6)$$

$$F_{net} = m \times a \quad (7)$$

$$Stroke_vel = \int Store_Acce \quad (8)$$

$$Stroke_displacement = \int Store_vel \quad (9)$$

A. Plant Model Working Principle

In the proportional valve working principle, when engine start is on and the valve powered on, more power received by the valve means more current that it can use in order to control the hydraulic oil pressure transmitted from the clutch in the manual mode of transmission

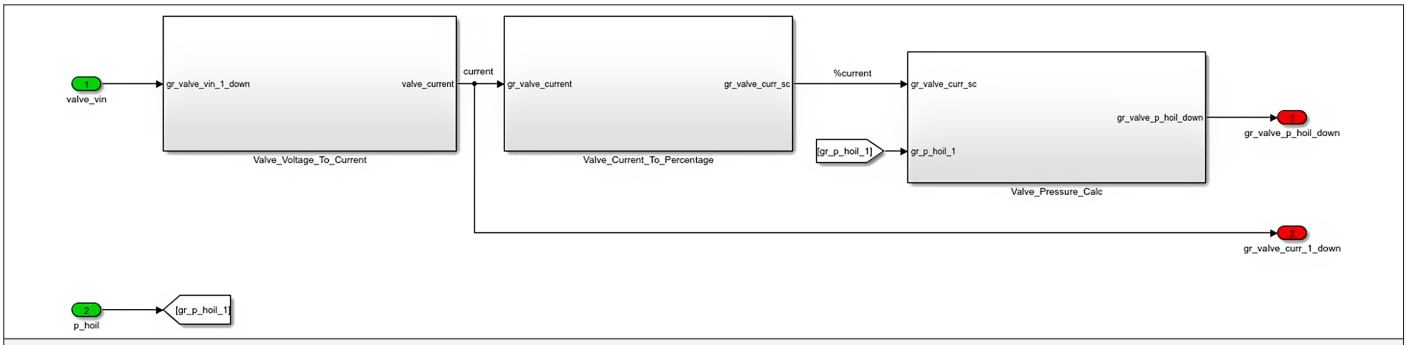

Fig. 1. Plant model, valve.

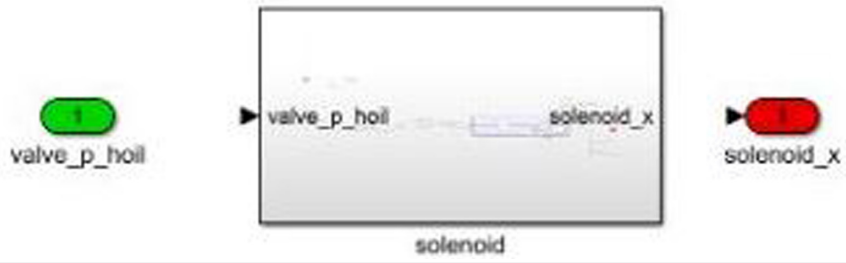

Fig. 2. Plant model, solenoid.

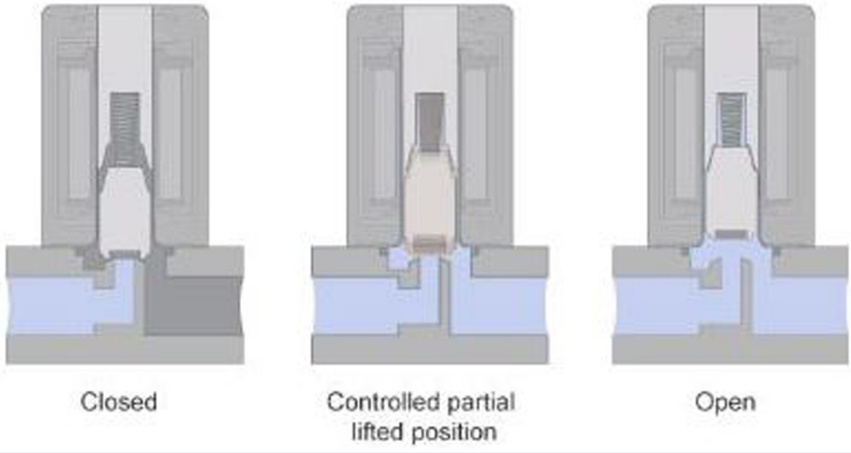

Fig. 3. Example of controlled solenoid.

of AMT for heavy duty vehicles [5]. Fig. 3 shows an example of controlled solenoids. The solenoid receives current-controlled hydraulic oil pressure in bar, and converts bar-to-Pascal. From (5), force is obtained, and then from (6), acceleration. From the integral of acceleration velocity, the double integral of acceleration is obtained, giving us the displacement of stroke.

The two-way solenoid is controlled by two valves. The first valve controls up-shifting of the solenoid, and the second valve controls down-shifting of the solenoid. As a result, the current controls the hydraulic oil pressure and the controlled hydraulic oil pressure keeps the piston stroke at the desired level.

III. PID CONTROLLER MODEL AND WORKING PRINCIPLE

There are three basic types of controllers: on-off, proportional, and the proportional integral derivative (PID) [6]. Depending upon the system to be controlled, the developer will be able to use one type or another to control the process [7]. A PID controller can be used as a means of controlling temperature, pressure, flow, and other process variables. As its name implies, a PID controller combines proportional control with additional integral and derivative adjustments which help the unit automatically compensate for changes in the system. The purpose of a PID controller is to force the feedback to match a setpoint. A PID controller is best used in systems which have a relatively small mass and those which react quickly to changes in the energy added to the process. It is recommended in systems where the load changes often and the controller is expected to compensate automatically due to frequent changes in setpoint. The working principle behind a PID controller is that the proportional, integral, and derivative terms must be individually adjusted or "tuned." Based on the difference between these values, a correction factor is calculated and applied to the input. Here are the three steps:

(a) Proportional tuning involves correcting a target proportional to the difference. Thus, the target value is never achieved because as the difference approaches zero, so too does the applied correction.
(b) Integral tuning attempts to remedy this by effectively cumulating the error result from the "*P*" action to increase the correction factor. However, rather than stop heating when the target is reached, "*I*" attempts to drive the cumulative error to zero, resulting in an overshoot.
(c) Derivative tuning attempts to minimize this overshoot by slowing the correction factor applied as the target is approached.

The analysis shows that the error recalculation anti-windup technique gives better reference tracking performance when compared to the incremental algorithm and back-calculation techniques, being able to reduce the effects of noisy measurements on the calculation of the control action, thus resulting in lower control and process variable variability [8].

This paper analyzes the PID controller with anti-windup and conventional PID control results. Fig. 4 explains PID controller with anti-windup (clamping circuit).

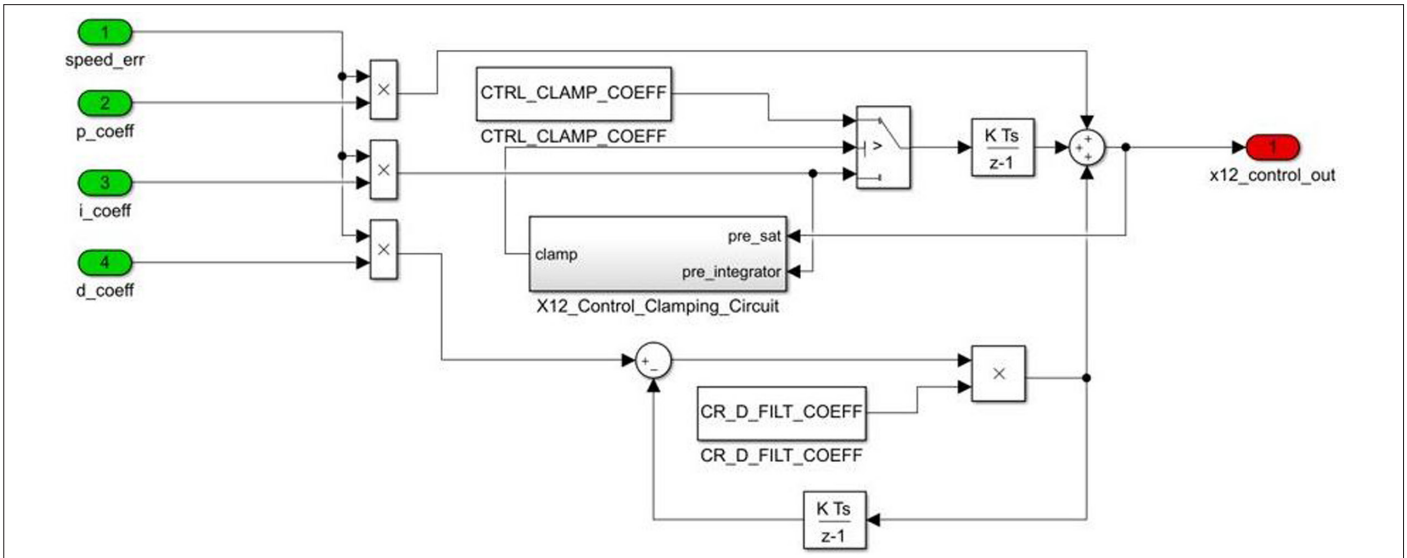

Fig. 4. PID controller model.

IV. CONVENTIONAL CONTROLLER MODEL AND WORKING PRINCIPLE

The PID tuner provides a fast and widely applicable single-loop PID tuning method for the PID controller blocks [9]. With this method, controller parameters are tuned to achieve a robust design with the desired response time. The conventional model reference controller in Fig. 5 shows the conventional controller model. The PID control method is one of the oldest and most used control methods in feedback controllers. Especially, conventional PID controllers have been used in many industrial applications since they have a simple structure that can be calibrated very easily and can be easily analyzed by system users. According to a study of process control systems in 1989, PID controllers comprised more than 90% of the control loops used. This widespread use has led many researchers to PID controller design. The two most common PID controller design techniques are techniques based on closed-loop tests and step-input tests for the proportional control state at the nominal operating point. The purpose of the design of a PID controller is to adjust the gain coefficients of *Kp*, *Kd*, and *Ki* (proportional integral derivative gain coefficients) and to adjust the system until the required answers are obtained according to the necessary requirements. That is, most of the time, PID design is performed within a process framework that can be controlled by an optimization cycle.

V. APPLICATION MODEL

In this section, two plant models are controlled by using the PID-anti-wind-up controller technique and the conventional PID controller technique. The results are demonstrated [10]. A clamping circuit (also known as a clamper) will bind the upper or lower extreme of a waveform to a fixed DC voltage level. These circuits are also known as DC voltage restorers. Clampers can be constructed in both positive and negative polarities. When unbiased, clamping circuits will fix the voltage lower limit (or upper limit, in the case of negative clampers) to 0 V. These circuits clamp a peak of a waveform to a specific DC level compared with a capacitively coupled signal, which swings about its average DC level. Therefore, the clamping circuit, which is used as anti-windup, stops integration with respect to the saturation level of PID [11]. Conditional integration is easy to apply to many controllers, although it may not be possible to immediately find the conditions to block integration and to avoid chattering. However, it only applies to PID control. The observer approach is very general and does not require tuning any additional parameter.

A. Controlling with PID – Anti-windup

The term "windup" was used to refer to a phenomenon associated with saturation in systems with integral controllers and alluded to the buildup of charge on the integrator's capacitor during saturation [12]. The subsequent dissipation of this charge would then cause long settling times and excessive overshoot, thereby degrading the system's performance. Modifications to the controller which avoided this charge buildup were often termed "anti-windup" modifications, and hence the term anti-windup was born.

Fig. 6 shows the controlled model and anti-windup PID controller model. The plant model is created with two valves, one for up-shift of the solenoid, and the other for down-shift of the solenoid. Fig. 6 shows a controller and system design model with anti-windup PID controllers.

The design pattern is created with two valves, one for the piston to slide up and the other for the piston to slide down. In other words, in line with the decision taken according to the characteristics of the system models for which two identical control models will be designed and the control design will be carried out, one of the valves to be designed, in light of the study to be conducted on the system control in the application software and the control model, will be designed and the control design will be carried out. The decision will be taken according to the characteristics of the system models. In the light of the work to be done on the system control in the application software, in line with the decision taken according to the characteristics of the system models, the other control model will be designed and the control design will be carried out in order to control the upward movement of the piston, which will be designed in light of the work to be done on the system control in the application software, in line with the work done on the system control. If the valve is to be designed and to be obtained as a result, the control model will be designed and the control design will be carried out. It is designed to control the downward movement of the piston, which

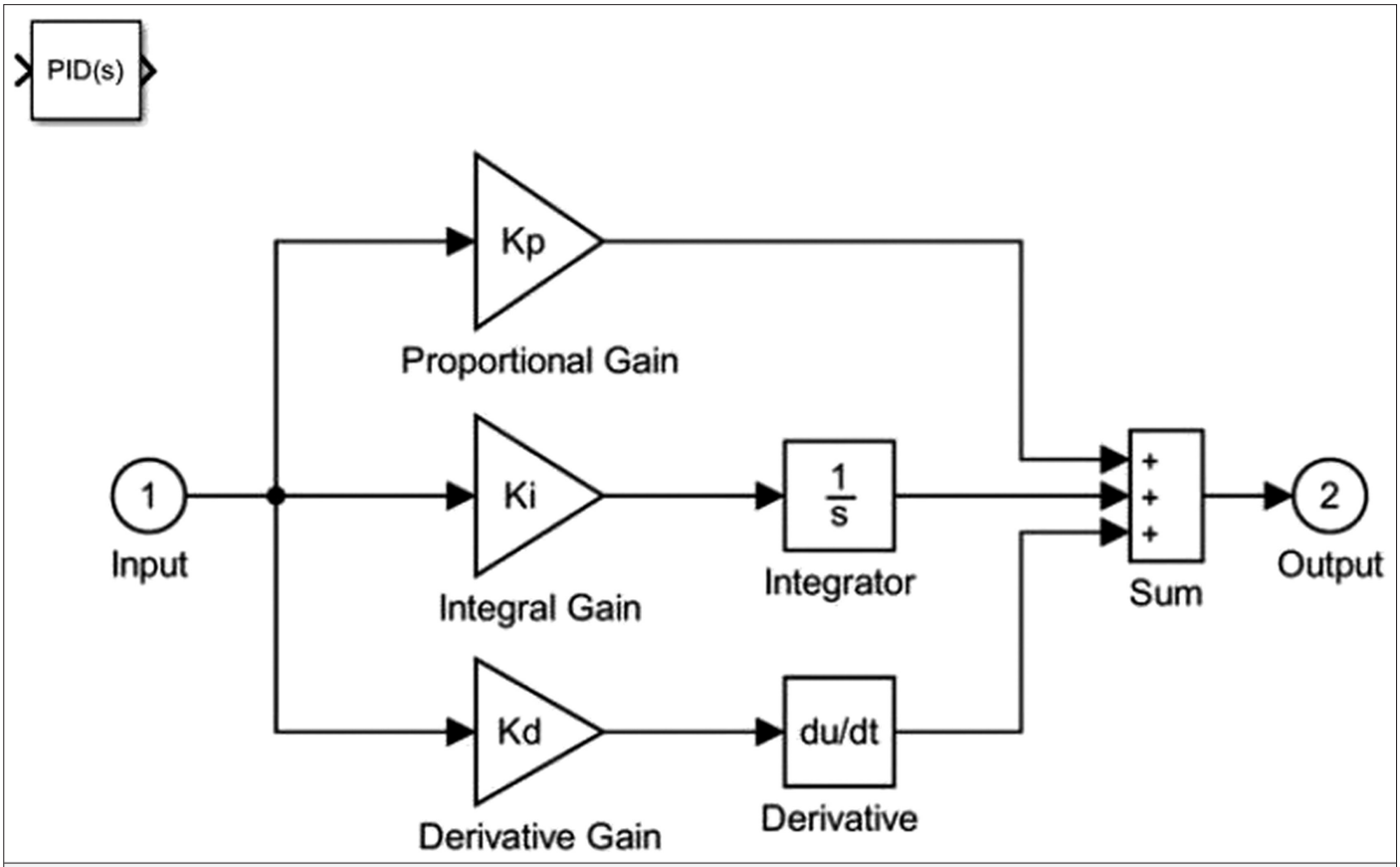

Fig. 5. Conventional PID controller model.

will be designed in the light of the work to be done on the system control in the application software, in line with the decision taken according to the characteristic features of the system models.

B. Controlling with Conventional PID

Fig. 7 shows the controlled model and the conventional PID controller model. The plant model is created with two valves, one is for up-shift of the solenoid, and the other is for down-shift of the solenoid.

The figure shows the controller and system design model with conventional PID controllers. The system design model will be designed in the light of the work to be done on the system control in the application software, in line with the decision taken according to the characteristic features of the system models to be designed, by designing two identical control models as in the anti-wind-up PID controllers and the controller and system design models. One of the valves will be designed based on the work to be done on the system control in the application software, in line with the decision taken according to the characteristic features of the system models for which the control model will be designed and the control design will be carried out. One of the valves is to be designed and the resulting control model will be designed and the control design will be performed (*P*), which will be designed in the light of the work to be done on the system control in the application software, in line with the decision taken according to its characteristic features and which will be obtained as a result. In order to control the upward movement of the piston, the other control model will be designed and the control design will be carried out in line with the decision taken according to the characteristics of the system models, and the valve design to be designed in the light of the work to be done on the system control in the application software. On the other hand, the control model will be designed and the control design will be carried out, which is designed to control the downward movement of the piston, which will be designed based on the work to be done on the system control in the application software, in line with the decision taken according to the characteristic features of the system models.

C. Analysis and Results

(1) Anti-Windup PID Controller Result

(a) Solenoid Control Result

Fig. 8 shows the result of the piston control with anti-windup PID controllers, and the controller and system design model. The

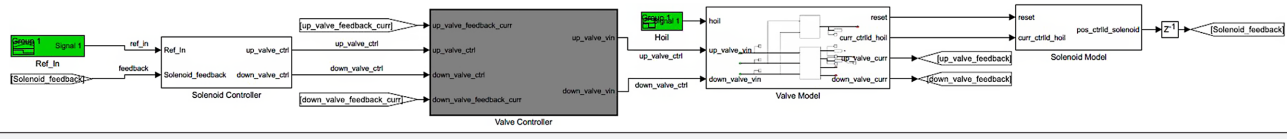

Fig. 6. Anti-windup PID controller.

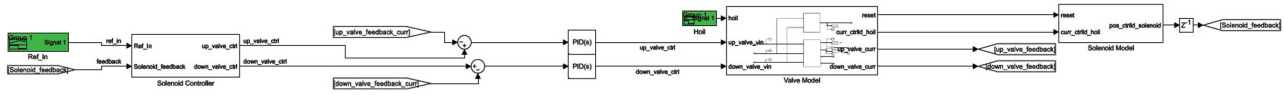

Fig. 7. Conventional PID controller.

hydraulic oil pressure output of the piston (whose reference input is maximum 6000 µm), which will be designed in the light of the work to be done on the system control in the application software, in line with the decision taken according to the characteristic features of the system models whose control model will be designed and the control design will be realized, and the hydraulic oil pressure output of the hydraulic valves controlled by current. As seen in Fig. 8, the piston position, controlled by the piston position control, has settled at the expected position level, the control model will be designed according to the conventional PID controller and the control design will be carried out in line with the decision taken according to the characteristics of the system models, which will be designed in the light of the work to be done on the system control in the application software. The fluctuation of the piston to be obtained is very low when it comes to the starting position. Thus, the conventional PID-controlled control model of the anti-windup PID controller will be designed, and the piston design model will be designed in the light of the work to be done on the system control in the application software, according to the decision based on the characteristics of the system models to be controlled. With anti-windup techniques, the most effective and utilizable anti-windup *PI* parameters are $P = 100$ and $I = 90$, and conventional *PI* parameters are $P = 0.009$ and $I = 0.941$, as shown in each result. According to the results, it has been concluded that it is more successful in terms of low fluctuation level, which is an important criterion among system requirements.

(b) Up Valve Control Result

Fig. 9 shows the result of the anti-windup PID controllers and the push-up valve control of the controller and system design model. The controlled control model will be designed and the control design will be carried out in line with the decision taken according to the characteristics of the system models, which will be designed in the light of the work to be done on the system control in the application software; the resulting valve reference input will be designed with a maximum current of 1734 mA. The valve, which will be designed in the light of the work to be done on the system control in the application software in line with the decision taken according to the characteristic features of the system models whose model will be designed and the control design will be carried out, and the resulting valve is almost at the expected current level as seen in Fig. 9, pushing it up compared to the conventional PID controller. The ripple is very low when the valve comes to the starting current level. With anti-wind up techniques, the most effective and utilizable anti-wind up *PI* parameters are $P = 100$ and $I = 90$, and conventional *PI* parameters are $P = 0.009$ and $I = 0.941$, as shown for each result. Thus, it has been concluded that the anti-windup PID controller is more successful in terms of lowering the ripple level, which is an important criterion among the system requirements, compared to the control design model of the upward pushing valve controlled by the conventional PID.

(c) Down Valve Control Result

Fig. 10 shows the result of the anti-windup PID controllers and the push-down valve control of the controller and system design model. The controlled control model will be designed and the control design will be carried out in line with the decision taken according to the characteristics of the system models, which will be designed in the light of the work to be done on the system control

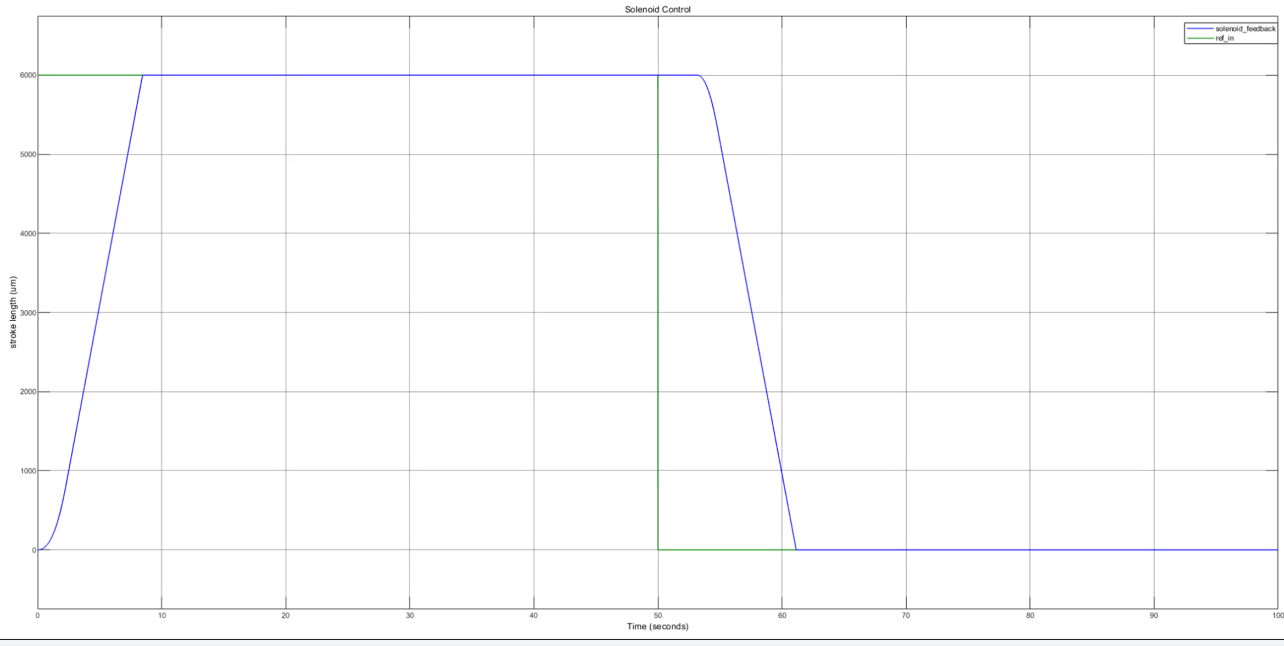

Fig. 8. Anti-windup PID-controlled solenoid control result.

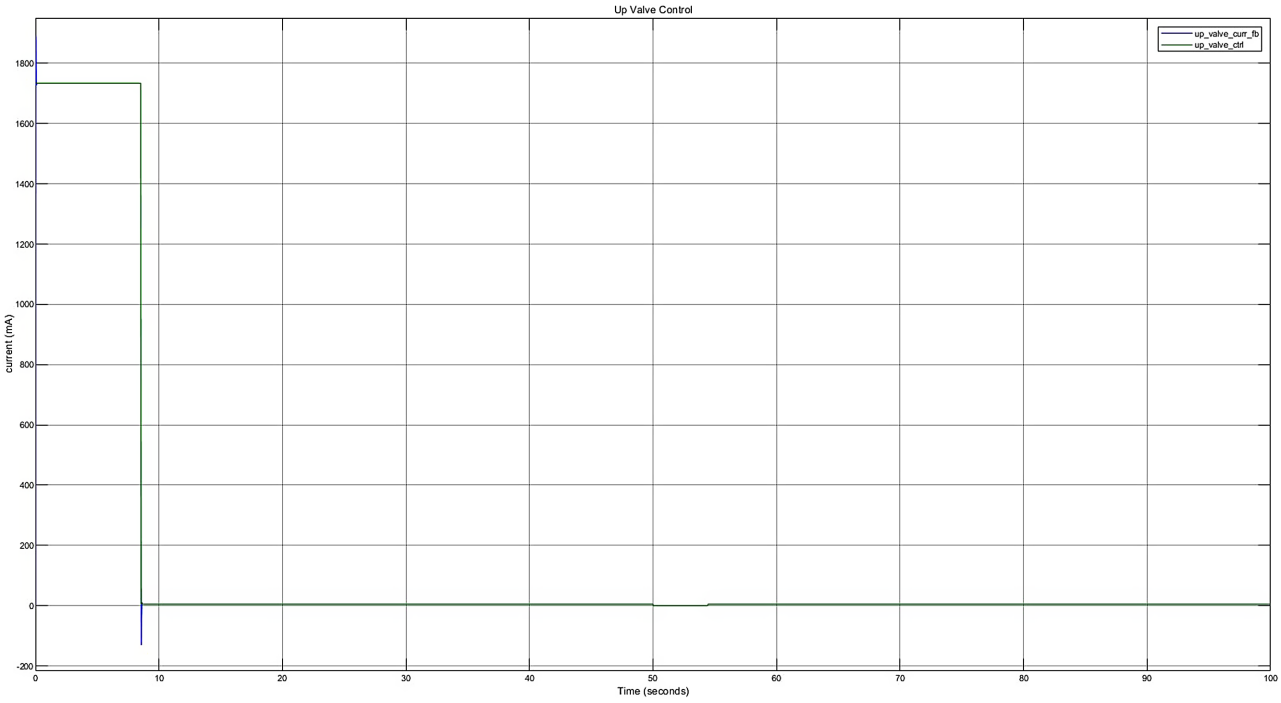

Fig. 9. Anti-windup PID-controlled up valve control result.

in the application software; the resulting valve reference input will be controlled with a current of maximum 1734 mA. The valve, will be designed in the light of the work to be done on the system control in the application software, in line with the decision taken according to the characteristic features of the system models, whose model will be designed and the control design will be carried out, and the resulting valve has settled at the expected current level as seen in F. The ripple is quite low when it reaches the initial current level. Thus, the anti-windup PID controller will be designed in light of the work to be done on the system control in the application software, in line with the decision taken according to the characteristics of the system models to be designed; the control model controlled by the conventional PID will be designed and the control design will be carried out. With anti-windup techniques, the most effective and utilizable anti-windup *PI* parameters are $P = 100$ and $I = 90$, and the conventional *PI* parameters are $P = 0.009$ and $I = 0.941$, as shown for each result. It has been concluded that the valve is more successful in terms of low fluctuation level, which is an important criterion among the system requirements, according to the control design model.

(2) Conventional PID Controller Results

(a) Solenoid Control Result

Fig. 11 shows the result of the piston control of the controller and system design model with conventional PID controllers. The controlled control model will be designed and the control design will be carried out in line with the decision taken according to the characteristics of the system models, which will be designed in light of the work to be done on the system control in the application software; the result will be the piston reference input of maximum 6000 µm, with the hydraulic oil of the hydraulic valves controlled by the flow. The piston position control, which is controlled by the pressure output, has settled at the expected position level, as seen in Fig. 11. According to the anti-windup PID controller, fluctuation is observed when the piston reaches its starting position. Thus, the anti-windup PID controller's conventional PID-controlled control model will be designed and the control design will be carried out according to the characteristic features of the system models, in line with the decision taken in light of the study to be made on the system control in the application software, and the resulting piston will be obtained. With the conventional PID controller result, the *PI* parameters are $P = 0.009$, $I = 0.941$, and $D = 0$, as shown for each result. .According to the design model, it has been concluded that it is more successful in terms of low ripple level, which is an important criterion among the system requirements.

(b) Up Valve Control Result

Fig. 12 shows the result of the push-up valve control of the controller and system design model with conventional PID controllers. The controlled control model will be designed and the control design will be carried out in line with the decision taken according to the characteristics of the system models, which will be designed in light of the work to be done on the system control in the application software; the resulting valve reference input will be designed with a maximum current of 1734 mA. The valve will be designed in light of the work to be done on the system control in the application software, in line with the decision taken according to the characteristic features of the system models whose model will be designed and the control design will be carried out; the resulting valve is almost at the expected current level, as seen in Fig. 12, anti-winding (anti-windup). According to the PID controller, fluctuation is observed when the valve pushing up comes to its starting position. With the conventional PID controller result, the *PI* parameters are $P = 0.009$, $I = 0.941$, and $D = 0$, as shown for each result. Thus, it has been concluded that the anti-windup PID controller is more successful in terms of lowering the ripple level, which is an important criterion among the system requirements, compared to the control design model of the upward pushing valve controlled by the conventional PID.

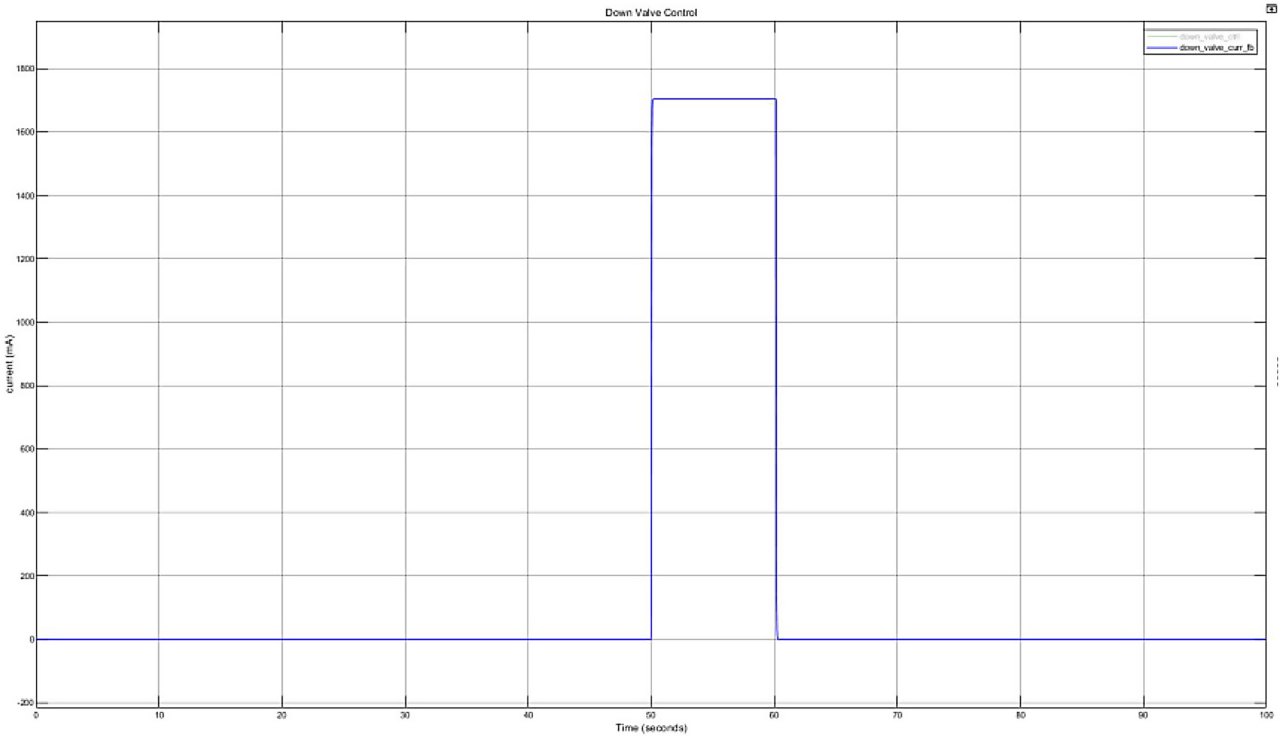

Fig. 10. Anti-windup PID-controlled down valve control result.

(c) Down Valve Control Result

Fig. 13 shows the result of push-down valve control of the controller and system design model with conventional PID controllers. The controlled control model will be designed and the control design will be realized according to the characteristic features of the system models, in accordance with the decision taken in the light of the work to be made on the system control in the application software; the resulting valve reference input will be controlled with a maximum current of 1734 mA (Fig. 13). As can be seen in Fig. 13, it has almost settled to the expected current level, a negative fluctuation is observed at the starting position of the valve pushing up, according to the anti-windup PID controller. Thus, the anti-windup

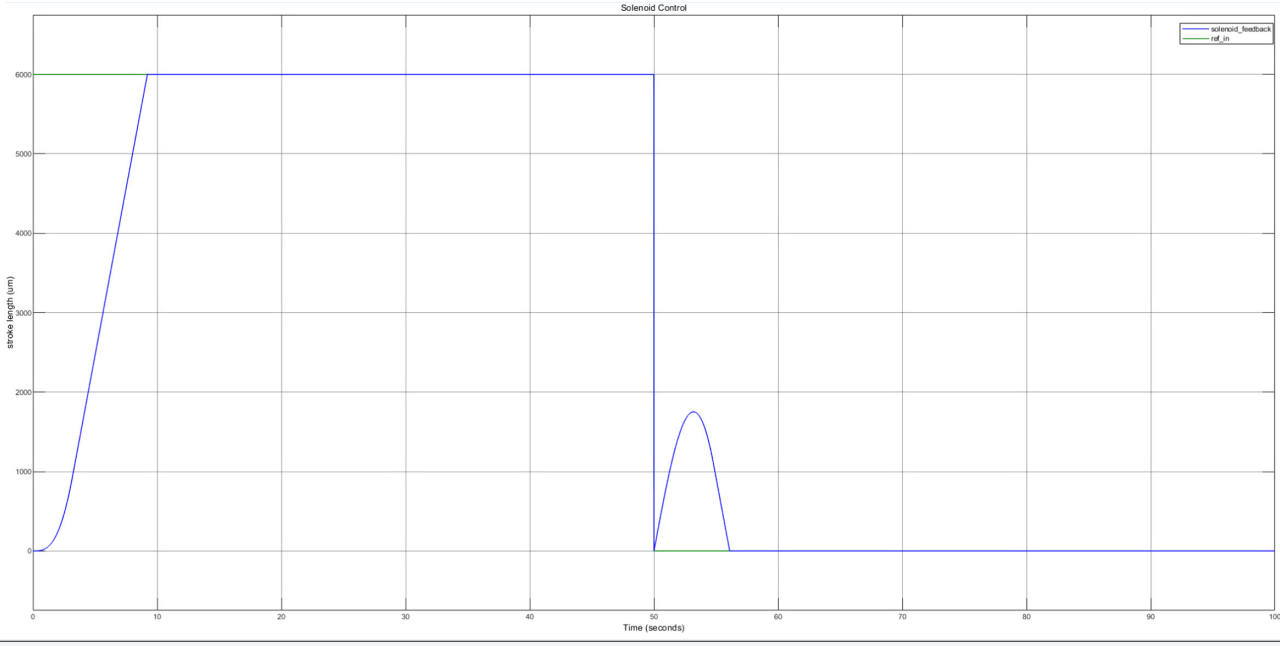

Fig. 11. Conventional PID-controlled solenoid control result.

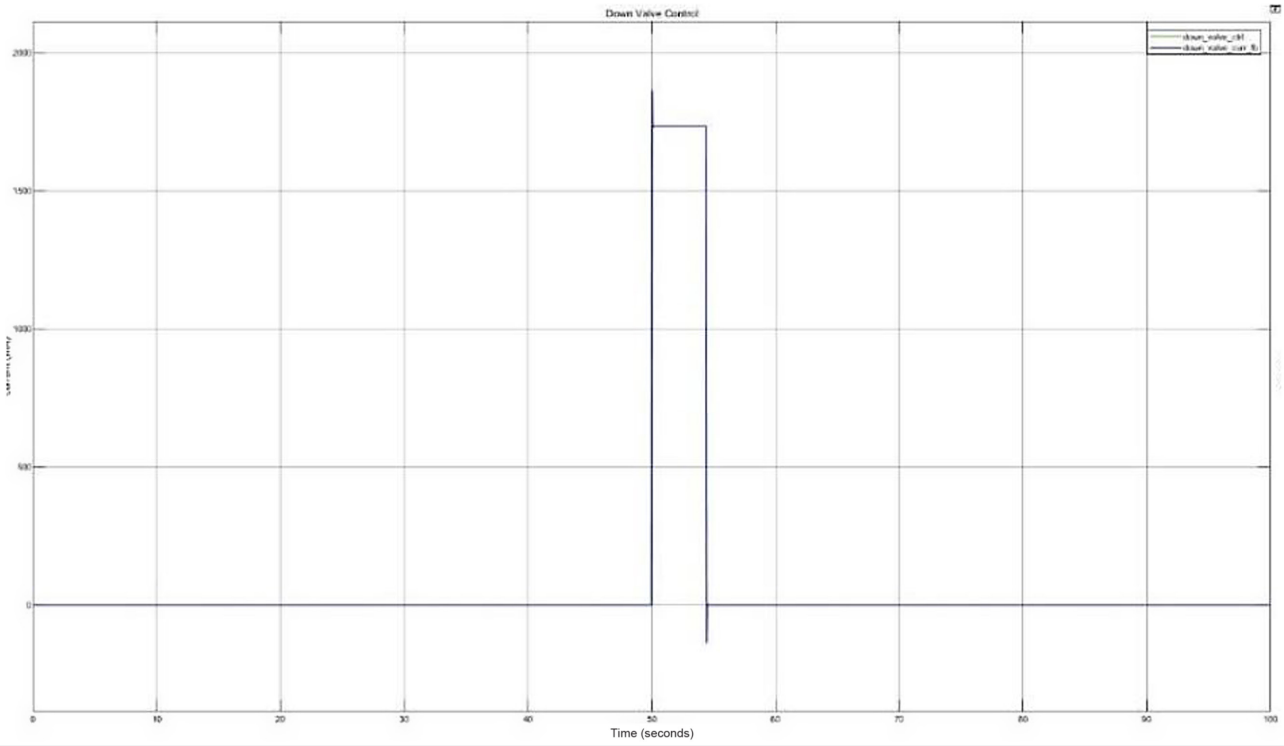

Fig. 12. Conventional PID-controlled up valve control result.

PID controller will be designed in the light of the work to be done on the system control in the application software, in line with the decision taken according to the characteristic features of the system models to be designed, and the control model controlled by the conventional PID will be designed and the control design will be carried out. With the conventional PID controller result, the *PI* parameters are $P=0.009$, $I = 0.941$, and $D=0$, as shown for each result. According to the control design model, the valve is more successful

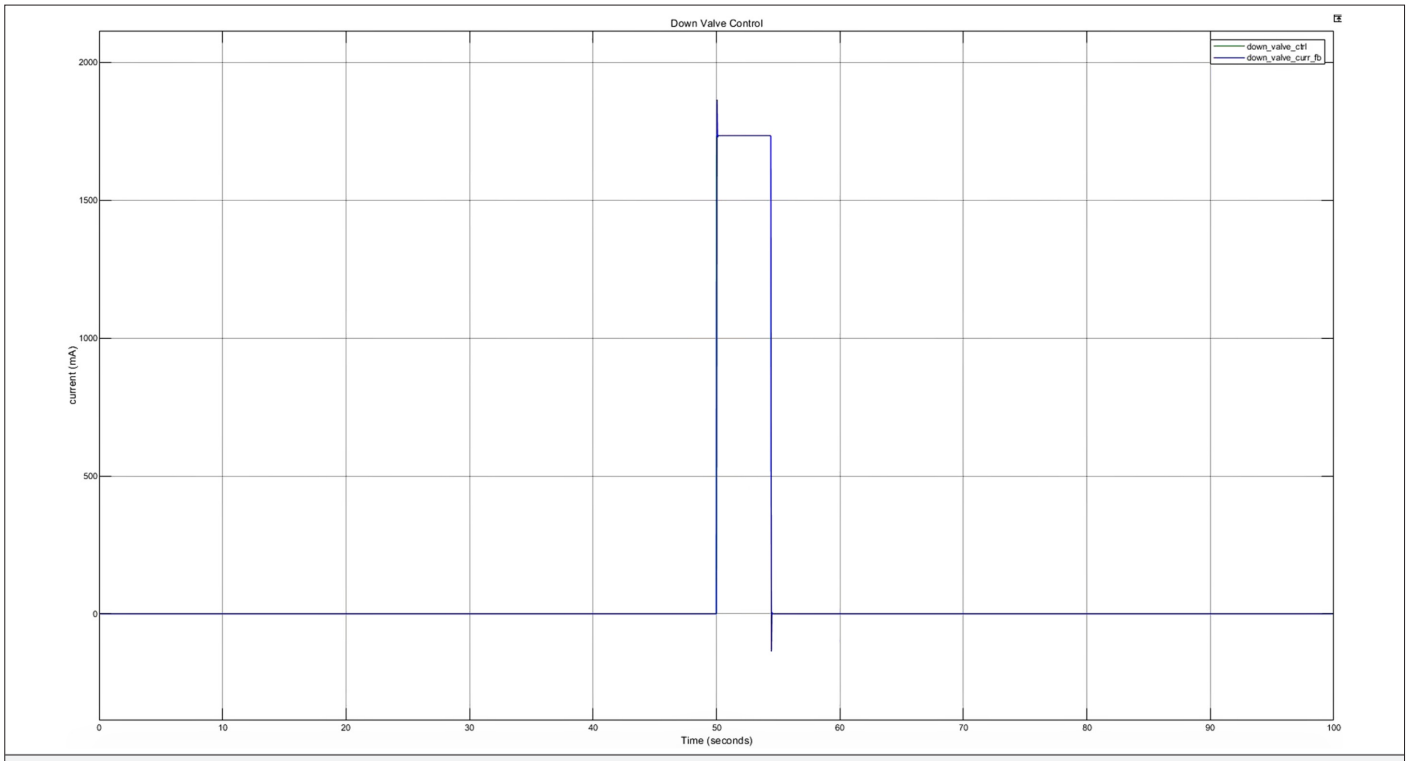

Fig. 13. Conventional PID-controlled down valve control result.

in terms of low fluctuation level, which is an important criterion among system requirements.

VI. CONCLUSION

This paper focuses on modeling the energized electro-hydraulic design models that make up the building blocks of the transmission component covered by the AMT architecture of some heavy duty vehicles, which are planned to be used in the defense industry and whose R&D activities are still ongoing. On the basis of developing different control techniques, these building blocks are controlled with different controllers and the results are analyzed.

This paper introduces some of the components used in transmission modeling of heavy duty vehicles. Secondly, this paper focuses on modeled PID controllers to explain and control the design pattern of these components. Third, the conventional controller, which is one of these PID controllers, is explained along with the studies on the design architecture. Fourth, the anti-wind up controller, which is one of these PID controllers, is explained along with the studies on the design architecture. Then, the checked results on the design models of two different controllers are taken and these results are analyzed. This explains the output of this heavy duty component.

According to the analyses in line with the announced outputs, the design and prototype of the other components that make up the AMT architecture are also targeted for future studies. In this paper, the other transmission components as a whole AMT model are indicated for future studies. Thanks to the valves that can control the flow and hydraulic oil pressure, and the effective displacement control of the piston, it is aimed to design and control two gear shift designs for each piston, as well as shift models for manual gear design using different control techniques. In line with this goal, as a result of this paper, it is aimed to use the anti-windup PID controller with the anti-winding technique, which is the most effective control technique.

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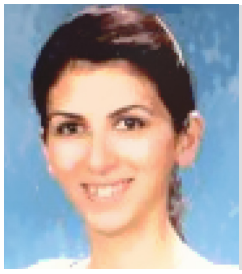

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