Avrupa Bilim ve Teknoloji Dergisi
Sayı 20, S. 506-515, Aralık 2020

Araştırma Makalesi

www.ejosat.com ISSN:2148-2683

European Journal of Science and Technology
No. 20, pp. 506-515, December 2020

Research Article

Electric Train Application Study For Catenary-Pantograph Interaction

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(First received 28 June 2020 and in final form 21 September 2020)

(**DOI:** 10.31590/ejosat.759407)

ATIF/REFERENCE: Parlakyıldız, Ş., Gençoğlu, M.T., Cengiz, M.S. (2020). Electric Train Application Study for Catenary-Pantograph Interaction, *European Journal of Science and Technology*, (20), 506-515.

Abstract

Today, electric rail systems that use clean energy and are a fast and reliable means of transportation are used more because of their efficiency. The main purpose of new studies investigating pantograph catenary interaction in Electric Rail Systems is to detect malfunctions. With the spread of high-speed trains in electric rail systems, malfunctions occur in pantograph and catenary systems operating under high current and high voltage. The contact force of the pantograph-catenary system erodes the pantograph surface and arcs occur. For this reason, periodic control is mandatory in pantograph-catenary systems. In this study, new, effective, sensitive, stable, real-time applicable and contactless condition monitoring, analysis, control, and diagnostic methods were investigated for pantograph-catenary systems that provide energy transmission from the electric line to the locomotive in electric trains. A literature search and study application after has been carried out for modeling a pantograph-catenary system and analysis of system parameters, instantaneous control of the contact force between the pantograph and catenary to diagnose malfunctions in the pantograph-catenary system. It has been observed that pantograph-catenary interaction is negatively affected and the quality of energy transmission decreases if the system parameters change for any reason. In pantograph-catenary systems, the importance of periodic pantograph control, which will ensure the stable and efficient operation of the system, is understood if the parameters change. Because changes in parameters cause malfunctions. Therefore, periodic control and continuous monitoring of the system is required.

Keywords: Electric rail systems, Pantograph-Catenary interaction, Pantograph, Catenary.

Katener-Pantograf Etkileşimi İçin Elektrikli Tren Uygulama Çalışması

Öz

Günümüzde temiz enerji kullanan, hızlı ve güvenilir bir ulaşım aracı olan elektrikli raylı sistemler verimlilikleri nedeniyle daha fazla kullanılmaktadır. Elektrikli Raylı Sistemlerde pantograf katener etkileşimini araştıran yeni çalışmaların temel amacı arızaları tespit etmektir. Elektrikli raylı sistemlerde yüksek hızlı trenlerin yayılmasıyla pantograf ve yüksek akım-yüksek gerilim altında çalışan katener sistemlerinde arızalar meydana gelir. Pantograf -Katener sisteminin temas gücü pantograf yüzeyini aşındırır ve ark'lar oluşur. Bu nedenle pantograf-katener sistemlerinde periyodik kontrol zorunludur. Bu çalışmada, elektrik hatlarından elektrikli trenlerde lokomotife enerji iletimi sağlayan pantograf-katener sistemleri için yeni, etkili, duyarlı, stabil, gerçek zamanlı uygulanabilir ve temassız durum izleme, analiz, kontrol ve tanı yöntemleri araştırılmıştır. Bir pantograf-katener sisteminin modellenmesi ve sistem parametrelerinin analizi, pantograf-katener sistemindeki arızaları teşhis etmek için pantograf ve katener arasındaki temas kuvvetinin anlık kontrolü için bir literatür ve uygulama çalışması yapılmıştır. Pantograf -Katener etkileşiminin olumsuz etkilendiği ve sistem parametrelerinin herhangi bir nedenle değişmesi durumunda enerji iletiminin kalitesinin düştüğü gözlenmiştir. Pantograf -Katener sistemlerinde, sistemin istikrarlı ve verimli çalışmasını sağlayacak periyodik pantograf kontrolünün önemi, parametrelerin değişmesi durumunda anlaşılmaktadır. Çünkü parametrelerdeki değişiklikler arızalara neden olur. Bu nedenle sistemin periyodik kontrolü ve sürekli izlenmesi gerekmektedir.

Anahtar Kelimeler: Elektrikli raylı sistemler, Pantograf- Katener etkileşimi, Pantograf, Katener.

1. Introduction

As in all areas, the biggest need for transportation is energy. Energy consumption is increasing day by day due to reasons such as requirements of modern life, increasing competition environment, cultural and social developments. The area where electric energy is used in transportation systems is Electric Rail Systems (ERS). Electric rail systems have been used in transportation for many years [1-6].

The most important elements in ERS are pantograph and catenary. Compatibility between pantograph and catenary is one of the most important issues in these systems. A pantograph is mobile and catenary is a fixed element. These two elements touch each other and move in ERS is provided. Therefore, having contact between them makes the system more complicated.

The current in pantograph is the most important source of failure in ERS. The pantograph is above the roof of the train and collects current from the overhead catenary line. The Catenary line is fixed to poles with support points at regular intervals along the railway line [7-9]. When the train moves, the pantograph moves along the catenary line and delivers electrical energy to the ERS. The contact between the catenary and the pantograph should be optimal. When the ERS speed increases, vibrations occur in the catenary line. This disrupts the interaction between the pantograph and the catenary. These vibrations negatively affect the contact between the pantograph and the catenary. Since the contact between the pantograph and the catenary is interrupted in electrical contact, wear and arc occur [8-10]. Rail systems are generally advantageous means of maintenance in terms of maintenance factors other than pantograph-catenary systems. So maintenance factor multipliers are high. Mechanical parts of ERS require very little maintenance for a long time [9, 10].

2. Catenary-Pantograph Interaction

The pantograph is modeled in a basic motion with a numerical formula. The finite element method is used for the catenary model. With this method, the catenary dynamic response was successfully estimated [11]. Ide et al. examined a nonlinear situation so that the contact force can be controlled at a constant value. He estimated the situation using a feedback control approach. State estimation was made by using a nonlinear observer. The predicted situations are linearized according to their knowledge with feedback [12]. Mahajan et al. examined the relationship between contact force and contact wire displacement in the pantograph catenary system, creating a second order-independent system model. The sensitivity analysis of pantograph parameters on the system was observed [13]. Carmine et al. in this study, it was made for the optimum design of a nonlinear controller of the pantograph-catenary system. The purpose of the nonlinear controller is to reduce the contact force caused by the pantograph-catenary interaction, as well as to suppress the mechanical vibrations of the pantograph mechanism. In this study, a method based on the Lagrange approach and Udwadia-Kalaba equations are taken into consideration. Numerical simulations, the nonlinear controller obtained in this research for the pantograph-catenary system, showed successful results [14].

In his study, Yifeng et al. created the dynamic model of the Pantograph-Catenary system. To conduct contact analysis, he used the nonlinear three-mass equivalent of a pantograph and the finite element method for the contact wire of the catenary. By changing the design parameters of the contact wire at different speeds, the effects on the contact force were investigated [15]. Zhang et al. tried to determine the current collection quality in pantograph and catenary systems. Adjusts pantograph parameters for flow. By keeping the other parameters constant and changing the pantograph peak mass, the effects on simulation were examined. When the weight is between 8-10 kg, a better performance was measured in terms of contact force [16]. Farhangdoust et al. made stability analysis using the second order-independent mathematical model and finite element method. He examined the effects of external forces on pantograph and catenary interaction. He analyzed the effect of change of mass, tension, velocity, and damping parameters on stability. Contact force values of two different speed values (50 and 100 m/s) were calculated. He analyzed static and dynamic behaviors and compared them with theoretical data [17].

Ambrosio et al. tried to optimize the interaction between pantograph and catenary. By optimizing the contact force by working on the pantograph's top suspension and trying to improve it. In this study, the standard deviation of the contact force is tried to be reduced. The optimization process is used the finite element method for the genetic algorithm catenary and the bulk mass approach for the pantograph. However, it was understood that trying to optimize only pantograph parameters would not be sufficient in terms of system performance [18]. Zhou et al. examined the effects of changing parameters determined for the Pantograph-catenary system on the dynamic performance of the system. In this study, the finite element method for the catenary, and the mass model for the pantograph was used. When the simulation results are examined, the model works well up to 250 km / h speed. These results were compared with the test data obtained from a hybrid test method consisting of a real pantograph and a mathematical model of the catenary, and the results were found to be compatible [19]. In his study, Rachid used linear matrix inequalities to improve current collection quality in high-speed trains. The simulation results were successful for a fixed speed value. However, this success was not achieved at variable speeds [20].

Chu et al. separation of the pantograph head from the contact wire is an arc source. Euler-Bernoulli model was proposed to measure the amount of contact loss with simulation. Lagrange multiplier method, Lagrange multiplier is used to define the contact between the pantograph head and the contact wire. Also, with the simulation, contact wire rise and contact strength were evaluated with the effect of reconnection. As a result of the analysis, it has shown that the contact force increases very much at the time of reconnection. These increases wear. Pantograph mass and hardness have been found to affect the rate of wear [21].

Kia et al. made comparisons between them by researching different catenary and pantograph models to examine the interaction and contact strength between pantograph and catenary. He used a multi-mass model for the pantograph. In this model, successful results were obtained for low speeds [22]. Huang, a separate fuzzy variable study was carried out for ERS to be stable and pantograph position control. In this way, the stability of the system was achieved [23]. Benet et al. proposed a mathematical model for pantograph-catenary systems where different contact wires exist. It is aimed to ensure perfect contact while the pantograph slides from these lines. With this study, the most suitable form of assembly has been determined [24]. In the study by Arias et al., a static balance equation for pantograph-catenary systems was created as a mathematical model. He tried to solve the static equation of the equation with a high-performance calculation algorithm. With this algorithm, both memory usage and processing time are shortened [25].

In Zhou et al. study, if two pantographs are present in the system, he examined the effects of the distance between these two pantographs. He analyzed the effects of single pantograph and double pantograph conditions on system behavior and the effects of two pantographs on each other. If the phases of the waveforms formed in the anterior and posterior pantographs are the same, it is understood that the contact quality deteriorates because this further increases the vibration [26]. There are many studies in the literature that use different techniques such as bulk mass, finite elements, or smart methods to model pantograph-catenary systems [27-32]. Studies are investigating the variables of contact force and vibration control [33-38]. Active control of the pantograph is more reliable for electric rail systems. Therefore, fewer system failures occur. With active pantographs, changes in the system are detected. According to these changes, the stability of the system is rearranged. Especially at high speeds, active-controlled pantographs are needed more. Because as speed increases, stability decreases for constant contact force [2, 3, 39, 40].

Mokrani et al. have developed an active system for contact force control by proposing a fuzzy floating mode controller logic based on the PID control rule. A third-degree independent model was created for the pantograph-catenary system [41]. Tan et al., in this study, pulses were detected with fiber optic sensors for real-time monitoring of the catenary system. This process provided the opportunity to view, measure, and record the data and make an analysis. A new method that combines mobile standard deviation and mobile Pauta criteria has been proposed. This method simplifies the sensing system over the conventional position method. He predicted the detection of wear and other mechanical effects in the pantograph-catenary system with high accuracy [42].

In his study, Garg et al. created a mathematical model of the pantograph-catenary system. This model includes an active control with PID control. It obtained the open-loop and closed-loop transfer functions of the pantograph-catenary system and examined the effects of the controller parameters using sensitivity analysis. Calculations were made taking into account the train speed. It has been observed that as the frequency of vibration in the contact wire increases, its sensitivity increases [43]. Yamashita et al. have provided a modern active control technique to reduce contact force variation in high-speed trains. He used two types of active control technology for the pantograph. These are PID active control and impedance control. Measurement results are given for both control techniques and it is stated that impedance control is more advantageous than PID control in terms of frequency response. As a result, it was concluded that both methods are complementary [44].

Rusu et al. proposed a numerical simulation method to analyze the dynamic behavior of the pantograph-catenary system and control the contact force. In the model created, the speed, instantaneous position of the pantograph, and the dynamic models of the catenary with pantograph were used. The aim is to reduce the contact force change [45]. Song et al. are combined with stimulating control, high gain observer, and PI control to actively control contact force. A smooth and quality contact has been confirmed by theoretical data [46]. Rebollo et al. proposed a model that synthesizes both the genetic algorithm and the PID controller. He compared the PID control and finite element method. As a result, using the PI controller instead of the PID controller, more successful results have been obtained [47].

Abdullah et al. modeled the catenary using the method of mass dynamics analysis. It has developed active pantograph control to reduce the effects of vertical vibrations of the pantograph body on contact force [48]. Abdullah et al., in the simulation results, the change of contact force at different speed values were analyzed. Situations with and without active controllers are compared. In these studies, the active pantograph was used to dampen vibrations and positive results were obtained [49-51]. Abdullah et al., in his side study, he created a fourth-order independent pantograph mathematical model as an active control system to reduce contact force variation. To achieve this goal, an active suspension system, skyhook shock absorber, and track tracking springs were used. It has been determined that the passive controlled situation is unstable. This affects the contact quality negatively [52].

Walter has created a flexible active control system using fuzzy logic for the pantograph-catenary system in Matlab. The system explained with a simplified mechanical model [53]. Bandi has created an active control system with closed-loop feedback to regulate contact force. It has achieved successful results to reduce vibrations. However, it has been seen that an integral receiver is required to eliminate the steady-state error [54]. Pisano et al. did not prefer the method of measuring a contact force in his study. He measured the displacement of the lower and upper frame by a different method. Thus, he estimated the contact force. According to these estimates, the upper frame controller was found to be more efficient in terms of the control approach [55]. Matvejevs et al. considered the development of special pantographs to reduce contact force effects. He modeled in Matlab-Simulink the results of active and passive control systems on simulation [56]. Xiaodong et al. have applied the self-adaptive active control method to the suspension of the pantograph-catenary system to reduce vibrations [57]. Taran et al. proposed an active predictive control model with closed-loop and horizontal motion estimation approaches. This model is used to determine the time-varying characteristic of catenary stiffness. The model gave good results for constant speed values [58].

Catenary-pantograph interaction studies for fault detection;

Active control of the pantograph is important for electric rail systems. Therefore, if the pantograph is actively controlled, less malfunction occurs. With active pantographs, changes in the system are detected. According to these changes, in ERS

- Stability of the system
- Movement of the pantograph in the horizontal direction,
- Pantograph-catenary balance,
- Change of pantograph-catenary force,
- Pantograph-catenary vibrations,
- Pantograph-catenary arc and abrasions

are the most important sources of failure. As in all other areas, periodic monitoring, fault detection, and prediction of maintenance time in ERS are important for sustainability. Basically, the controls focus on two important points. These are the monitoring of the rail profile and the catenary line. Wear, breaking, bending, the catenary line stretching, contact status, compatibility of the catenary line, and pantograph axis are examined. In this way, unexpected failures are foreseen. Increased speed in ERS increases electrical failures. For this reason, it is very important to detect faults in railroad systems and to determine appropriate inspection techniques [2, 3, 59, 60].

Bryja et al., the effect of vibrations on the pantograph-catenary system were analyzed by mathematical calculation. Vibrations in the rail system increase non-contact in the pantograph-catenary system. The vibration that occurs is a big problem, especially in high-speed rail systems. Pantograph vibrations calculated for two trains with a speed of 60 km/h and 100 km/h were calculated. Pantograph vibrations increased contact loss in the catenary-pantograph system when single-stage train suspension was used. In two-stage suspension, contact loss was reduced in pantograph-catenary systems. Efficiency has been directly proportional to the increase in train speed. The two-stage suspension was successful. Therefore, high-speed sudden shocks did not affect the pantograph-catenary system [61].

In his study, Wang et al. emphasized that the pantograph contact strip and contact wire form a friction pair and analyzed wear. It used a high performance sliding contact test machine to obtain experimental data. He tried to create a mathematical model. He investigated the effects of electrical and mechanical wear depending on the change value of the contact pressure. It has been observed that electrical wear occurs for small values of contact pressure and mechanical wear occurs for large values. When the speed increased, the contact points were passed faster and the heat generated was lower. When speed decreased, temperature, and wear increased due to friction [62]. Ding et al. examined the carbon contact strip of the pantograph with the copper contact wire of the catenary. Arc and wear of the pantograph-catenary system were analyzed. It evaluated the rate of wear according to the electric current. Accordingly, it was observed that the wear rate increased during the arc [63, 64].

Östlund et al. explain that an arc occurs between the contact wire and the contact strip due to icing in the winter. It measured DC components on train sets. It observed arc-induced wear. Current information, voltage, speed, arc signals were recorded [65]. Ocoleanu et al. examined the temperature coefficient values against the different current values obtained from the experimental data. He evaluated the overheating and friction failures caused by the friction of the pantograph and the catenary. Calculated error values for overheating and friction failures [66]. Nituca is the model for the contact pair, where the pantograph is made of graphite and the contact wire is made of copper. The highest contact temperature and heat distribution were determined for these two components. The model created provides an explanation of thermal events for different materials under different conditions [67].

The intensification of the electric arc and related electrochemical corrosion on the pantograph-catenary system creates mechanical and thermal damage. Therefore, excessive wear occurs. The pantograph-catenary system has been compared in terms of electrical and mechanical properties as carbon wire and conventional wire. For this purpose, a physical experiment platform was designed. In this study, the traditional Pantograph-catenary and the new circular pantograph system were compared. The new Circular pantograph-catenary system has shown superior performance both electromagnetically and thermally. The new system provided less friction heat, better heat dissipation, and improved catenary tracking performance [68-70].

Bucca et al., tests have been carried out in the laboratory for wear analysis at different speeds, different contact forces, and different current values on the contact strip made of different materials. According to this information, a simulation was created. With the simulation studies, the rate of wear was determined according to the current change. Wear the amount increased when the copper strip was used [71]. Midya et al. examined current and voltage values for arc faults in pantograph-catenary systems. It has created a model structure that represents the pantograph and catenary system. He examined current and voltage signals in order to determine the arc types in the model with current and voltage values [72].

A hybrid model that provides contact between the Facchinetti et al., pantograph and catenary was used. An application has been proposed to solve the arc, heating, and wear problems that occur with this developed model [73]. In his study, Yaman et al. have developed the arc detection approach using a pantograph model determined for fuzzy logic-based for pantograph-catenary systems [74]. Wei et al. abnormal wear in pantograph-catenary systems increase maintenance costs. Abrasion adversely affects the stability and safety of pantograph-catenary systems. In this study, models of calculating the wear rate in pantograph-catenary systems are proposed. These models have been used to approximate the wear of the contact wire and pantograph strip. According to this study, according to the wear estimation method proposed in pantograph-catenary systems, contact wire made of suitable material should be used to reduce the formation of deep grooves in the contact wire [75].

In his study, Tu examined the Cf/Cu-C contact strip under the electric current for pantograph-catenary systems and the wear behavior of the material [76]. In his study, Er made catenary line icing prevention applications for urban light rail transportation systems in pantograph-catenary systems. He repeated his practice in the laboratory environment with field experiments in the outside area [77]. Guiming et al. in the study carried out, the carbon wire wear of a pantograph on trains at 250 km / h is very high. The sliding wire has been found to be severely worn under electric current. For this purpose, applied tests were carried out. Experiments on the high-speed railway were carried out at electric currents of 200, 300, 400, and 500 A and at speeds of 100, 150, 200, and 250 km/h. Friction coefficient, wear volume, arc electric current, arc electric voltage drop and carbon friction temperature increase were recorded. The test results show that the friction wears volume increases in direct proportion to the electric current. Accordingly, arc melting has been found to increase wear [78]. Er, in his study, the friction and wear behavior of carbon strip/copper contact wire in electric rail transportation vehicles pantograph-catenary systems were investigated [79]. By measuring the distance between the locomotive peak and the pantograph, Jian-Ping has developed a dynamic measurement method based on laser phase spacing technology. In addition, arc, vibration, wear, friction, and thermal analyzes were made. [80-84].

3. Solution Methods Used in Pantograph-Catenary Systems According to The Type of Fault

Many et al. studies have been carried out for fault diagnosis in pantograph catenary systems. In these studies, different solutions for malfunctions have been provided by many different methods [2, 3, 85-87]. Gregori et al., in this study, it is proposed to use an offline/online coordinate approach together to create a very efficient simulation strategy. Instant real data was used for hardwarein-the-Loop (HIL) simulation. This new approach produced higher accuracy results compared to results obtained with conventional finite element strategies. Simulation results showed that the proposed method can be used to perform pantograph HIL tests [88]. In his study, Koyoma investigated faults caused by the wear of the pantograph contact strip and the upward movement of the pantograph. Using accelerometers, he analyzed deviations from the contact force and axial force in the transmission wire [89].

Zhenghua et al., stable and accurate contact point in pantograph-catenary systems is an important factor for measuring geometric parameters. In this study, a method is used to detect contact points from infrared images. Horizontal-vertical enhancement (HVE), horizontal image layer (HIL), and vertical image layer (VIL) were used. Successful results with 99.6% accuracy were obtained for contact point detection [90]. In independent studies, Barmada et al. and Midya et al. investigated DC current change and arc faults caused by pantograph arc in their studies. Using current and voltage measuring sensors, he experimentally analyzed the relevant parameters, analyzed using support vector machines and fuzzy logic [91, 92]. Zhu et al., in this article, a nonlinear partial state feedback control are designed for the 3-DOF pantograph-catenary system using the loopback approach so that the contact force of the closed-loop system can follow the reference profile. In the control design, the pantograph-catenary model has been converted into a triangular form. This facilitates feedback. According to the calculation made, the proposed nonlinear feedback has achieved successful results. With nonlinear feedback control, the amount of error of the contact force was seen in the simulation [93].

Also being independent studies, Liu (2010), Li (2009), ODonnell (2006), Baguslavskii (2006), Landi (2006), Barmada (2003), Ding (2011), respectively;

• Determination of the position of the contact wire with the pantograph and the interaction between the two

• Monitoring the condition of the pantograph strip

• Contact performance of the contact wire

• Evaluation of contact performance

• Determination of the height of the contact wire

• Excessive friction, incorrect static contact force

They tried to find solutions to the types of malfunctions. They used methods such as edge extraction and structural geometric modeling, analysis of pantograph contact force, determination of the contact wire height with an artificial neural network, various segmentation methods, hough transformation, line segment detection and mean shift object tracking algorithm [94-101].

Huang et al., the occurrence of arcs in pantograph-catenary systems damage rail operations. A CNN-based model has been proposed to prevent arc-induced failures. Pantograph videos recorded by a camera fixed on the High-Speed Train were recorded. CNN model is trained with sample failures. 95% correct information has been reached. The formation and size of arcs are determined correctly. It has been found that the CNN model can be applied to other EMU models or environments with adjusted parameters [102]. In his study, Hallgrimsson examined the malfunction of the pantograph contact wire overheating and wear. He analyzed the pantograph-catenary system using a wavelet analysis method using phototubes [103].

Being et al. independent studies, Zhang and Midya investigated pantograph contact wire performance problems in their studies. They created arc models and examined arc current and arc voltage [104, 105]. Farhan et al. this study used the Safe Experiment Dynamics method to adjust fuzzy logic controller parameters. A single input fuzzy logic controller is proposed to control the contact force between pantograph and catenary. In this way, the controller is designed with fewer variables than other existing models. The performance of the fuzzy logic controller was analyzed for pantograph time response and contact force. A simplified model of the three degrees of freedom (3-DOF) pantograph-catenary system was used. Successful results were achieved with a rapid response within 5.27 sec, with a deviation of 2% from the real force [106]. In his study, Jie investigated malfunctions caused by pantograph-catenary interaction and catenary vibration. It provided solutions for changes in the pantograph-catenary system with signal processing using optical fiber [107].

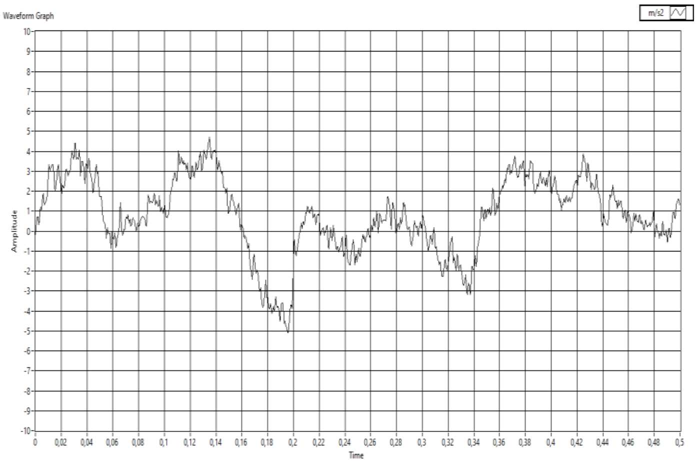
Tan et al., fiber Bragg grating sensor system is an important sensing element for strain measurements. In this study, a fiber Bragg grating sensor system was mounted on the pantograph catenary system. In the test conducted, it was observed that the temperature of the pantograph strip reached about 80 °C while the vehicle was running. Time-domain and frequency-domain analyzes of the contact force compensated by the proposed method were performed. With the designed filter, the effect of temperature on strain signals is eliminated. This method is more effective in predicting the actual tension of the pantograph strip compared to the traditional temperature compensation technique [108]. In his study, Babillot et al. tried to find solutions to the failures arising from the upper contact wire and the transmission wires in the pantograph-catenary system. He analyzed the causes of malfunctions using signal processing and wavelet analysis using video image recording [109]. In addition, in many studies, mathematical models have been created to find solutions to malfunctions caused by pantograph-catenary interaction. Analyzes were carried out on electric rail systems using hardware simulation techniques [110-113]. All simulation studies in rail systems and other energy systems aim efficiency optimization [114-121].

4. Material and Method

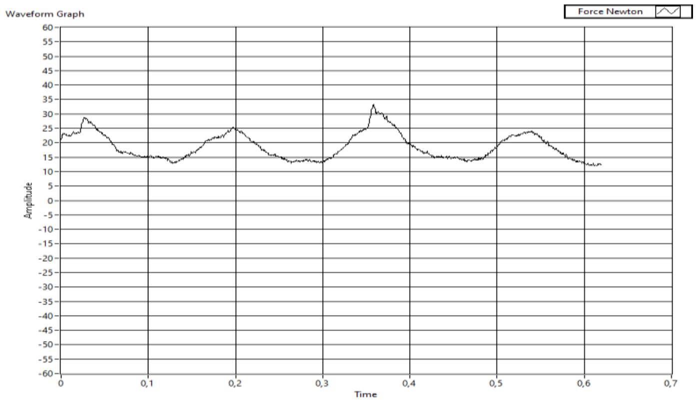
In this study, sensors were added to the pir pantograph to examine the failures of the components that make up the railway line. With these sensors, the fault locations were determined by looking at the signals from the accelerometer and force meter. Fault detection and fault point are detected very quickly. Error information was detected from signal change. In this way, the spring formed in the interaction between the catenary and the pantograph was seen.

As a result of the measurements carried out physically in the test environment, the signals received from the electric train are shown in Fig. 1, and Fig. 2. In Fig. 1, the electric train is in motion (no malfunction), (a) signals from the accelerometer (b) signals from the force sensor. In Fig. 2, the electric train is in motion (at the time of failure), (a) signals from the accelerometer (b) signals from the force sensor [113].

Figure 1.a and Figure 1.b shows the normal operation of the electric train in motion. In normal operation, the signals received from the accelerometer and force sensor are seen. While there is no breakdown in the electric train, the lower and upper ends of the signals in the system are close to each other. Figure 2.a and Figure 2.b show the operation of the electric train in motion at the time of failure. While the electric train is in motion, the signal change from the accelerometer at the time of failure is seen with an abnormal signal change up and down. In the signals coming from the force sensor, the signal change at the time of failure is abnormally downward.

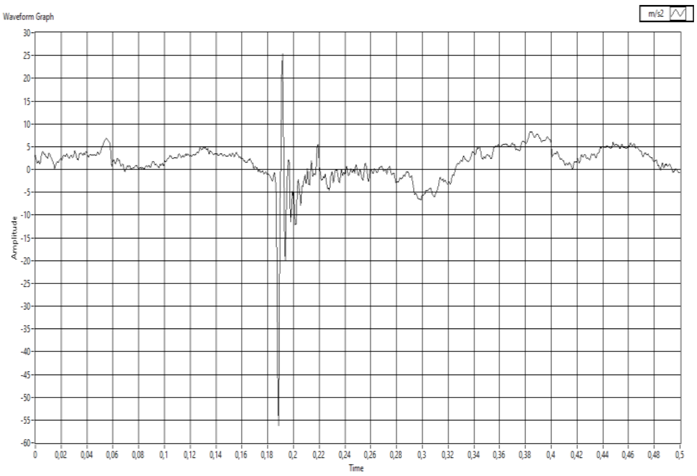


a) Electric train in motion (no fault), signals from accelerometer

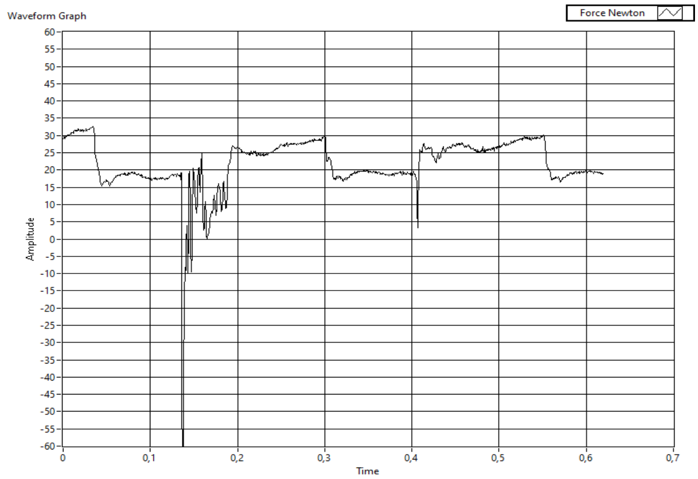


b)Electric train in motion (no fault), signals from force sensor

Figure 1. Electric train in motion (no fault), (a) signals from the accelerometer (b) signals from the force sensor



a)Electric train in motion (at the time of failure), signals from accelerometer



b)Electric train in motion (at the time of failure), signals from the force sensor

Figure 2. Electric train in motion (at the time of failure), (a) signals from the accelerometer (b) signals from the force sensor

5. Conclusions

Generally, the parameters of the contact wire or the pantograph parameters are emphasized. When the contact wire and pantograph parameters were evaluated together, more successful results were obtained. Studies for modeling the pantograph-catenary system generally yielded successful results for the constant train speed value. However, it was seen that erroneous results were produced with the change of speed.

The materials from which the pantograph catenary system is manufactured, the characteristics of these materials, their parameter effects, their behavior according to the seasonal conditions, the current draw values, the speed values of the system, and the changes in the contact force are different. Many factors such as wear, friction, arc, temperature, and vibration that cause malfunction should be analyzed in order to examine the failures that occur in the studies. Because when one of the negative parameters emerges, it is exposed to other negative conditions. Therefore, many parameters should be evaluated in modeling instead of just one negative parameter. Instead of a negative variable, an analysis should be made by considering more than one variable.

Studies have shown that pantograph-catenary interaction is negatively affected if the system parameters change for any reason. Accordingly, it is seen that the quality of energy transmission decreases. In pantograph-catenary systems, the stability of the system decreases if the parameters change. The necessity of periodic pantograph control, which will ensure the efficient operation of the system, is revealed.

5. Acknowledge

This work has been supported by the Scientific and Technological Research Council of Turkey (TUBITAK) under Grant EEEAG-118E322.

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