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AUTOMATIC CONTROL AND ROBOTICS

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Evaluation and development of a method for compensating the positioning error of computer numeric control equipment

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Abstract
In the manufacturing process, Computer Numerical Control is widely used to process products that require a high level of accuracy. It is found that during product processing, Computer Numerical Control is still unable to fully counteract the influence of vibration and the presence of uneven product surfaces. In this paper, the stabilization mechanism developed, known as the Modified Stewart platform, which has a 3 Degrees of Freedom and can rotate around the *X* and *Y* axes and move translationally along the *Z* axis. This platform can be used to improve the accuracy and stability of the Computer Numeric Control tool. In this research, the positioning accuracy of the Modified Stewart platform has been evaluated. In this research, a mock-up or prototype and a simulation model of the Modified Stewart platform was developed. The data to be studied is the inclination angle of the platform. In the experiment, to determine the positioning error, the variable being changed acquires not only the linear movement, but also the angle of the *X-Y* plane. By changing the angle contained in the *X-Y* plane, it can be seen the influence of the *X-Y* angle on the position error or angle of the *Z-A* plane. The simulation was carried out on MATLAB. The mathematical model in this study is to find the platform position or angle. To simplify the calculation, the Modified Stewart platform was depicted in the form of a trapezoid. The results of the angle in the simulation will be compared with the result of the angle on the mock-up Modified Stewart platform. The trapezoidal parameter used in the simulation corresponds to the parameters on the mock-up modified Stewart platform. The simulation provided information about the angle of inclination, height, length of its sides, and the relative length of sides. It was found that the position or angle movement of the platform is in accordance with the calculation or simulation model that has been developed, and the positioning error data of the platform is very small and it changes constantly. It should be noted that the presented method can be used to evaluate the platform positioning error and consequential calibration of the mechanisms with spatial kinematic. The positioning error at various mobile links positions is changing, but during the movement in just one direction it remains almost constant. The position error caused by the platform mechanism can be minimized by redesigning the platform and using components that can provide a much more precise movement, moreover, using the preliminary measurements it is possible to build a table containing corrections for the control program to access the correct position of the moving platform. The accuracy and the stability of its movement can be improved and the platform can be applied to Computer Numerical Control. The method developed allows to estimate the moving platform positioning error of the mechanism with spatial kinematic. Thus, the method developed can be eliminated or compensated. It is possible to calibrate the moving platform movements in automatic mode as well.

Keywords
modified stewart platform, computer numeric control, CNC, control, vibration, stabilization

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УДК 681.5.073

Оценка ошибки и разработка методики компенсации погрешности позиционирования оборудования с числовым программным управлением

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Аннотация
Предмет исследования. В процессе изготовления изделий с высокой степенью точности широко используется оборудование с числовым программным управлением. Известно, что в процессе изготовления изделий числовые программные устройства до сих пор не позволяют скомпенсировать влияние вибраций и связанное с ними появление неровностей на поверхности изделий. Предложена модифицированная платформа Стюарта, которая обладает тремя степенями свободы и может вращаться вдоль осей *X* и *Y*, и линейно перемещаться вдоль оси *Z*. Такая платформа может быть использована для увеличения точности и стабилизации в оборудовании с числовым программным управлением. Выполнена оценка точности позиционирования модифицированной платформы Стюарта. **Метод.** Разработаны макет и симуляционная модель модифицированной платформы Стюарта. В качестве данных для сравнения использованы углы наклона платформы. В ходе эксперимента для определения ошибки позиционирования изменена не только величина линейного перемещения, но и угол в плоскости *X–Y*, изменение которого показало влияние на величину ошибки выставления угла в плоскости *Z–A*. Симуляция проведена в программе MATLAB. В результате получен угол поворота платформы. Выполнено сравнение результатов расчета углов наклона модели и макета модифицированной платформы Стюарта с соответствующими размерами. Модель предоставляет данные об угле наклона, высоте, длине сторон и их относительном удлинении. **Результаты.** Обнаружено, что угловое перемещение платформы согласуется с предварительно вычисляемым положением согласно разработанной симуляционной модели, а ошибка позиционирования мала и постоянна. Предложенный метод может быть применен для оценки ошибки позиционирования платформы и дальнейшей калибровки механизмов с пространственной кинематикой. В ходе перемещения подвижного звена изменение его пространственного положения влияет на возможность перемещения остальных звеньев. При этом величина ошибки позиционирования при разных положениях подвижных звеньев изменяется. Показано, что в одном направлении погрешность остается практически неизменной. Погрешность механизма позиционирования платформы может быть уменьшена путем изменения конструкции платформы и использования деталей, обеспечивающих более точное перемещение. На основании предварительных измерений возможно построение таблицы с поправками, к которой будет обращаться управляющая программа для корректировки пространственного положения подвижной платформы. Точность и повторяемость перемещений могут быть улучшены, что позволяет применить платформу в оборудовании с числовым программным управлением. **Практическая значимость.** Разработанная методика позволяет проводить оценку погрешности позиционирования подвижной платформы механизма с пространственной кинематикой. Таким образом, ошибка позиционирования подвижной платформы может быть уменьшена, либо скомпенсирована. Представляется возможным обеспечение калибровки подвижной платформы в автоматическом режиме.

Ключевые слова
модифицированная платформа Стюарта, числовое программное управление, вибрация, стабилизация

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Introduction

The manufacturing process is a very complex one that involves many interactions between humans and machines. In the manufacturing process of a product, the thing that is very concerned is the quality of the product [1, 2]. Currently, the manufacturing process is more modern, which means that it relies on the use of machines to process its products compared to processes carried out by humans. So the quality of the product is very dependent on the results of the production machine process. In the manufacturing process, one of the causes of decreased product quality from production machines is vibration. This vibration reduces the accuracy of the production machine so that it can reduce the quality of the manufactured product. Moreover, if the product is measured in micron units, the accuracy of the machine is very important. This usually happens in the manufacturing process of electronic products or other sensitive products that require a high level of accuracy or a very small error. In the manufacturing process, for the processing of products that require a high level of accuracy, it is necessary to use Computer Numerical Control (CNC). However, it is found that during product processing, CNC is still unable to fully counteract the influence of vibration, thus reducing accuracy and increasing error, and reducing the quality of the product. It is also known that in addition to vibration, another factor that causes a decrease in CNC accuracy is the presence of uneven product surfaces. This is because there are differences in calculations between the program on the CNC and the actual product surface. CNC cannot know and detect the surface flatness of the product being processed and cannot move adaptively to it [3–5]. To increase the accuracy of the CNC and reduce errors caused by vibration and uneven product surfaces, a stabilization system is needed.

Vibration stabilization systems have been widely developed and applied to various devices such as cameras. The stabilization system on the camera is needed to reduce the influence of vibration on the optical part so as to provide better results. There are several technologies applied in the development of camera optical stabilization systems. Stabilization system technology uses a voice-coil actuator mechanism [6]. In addition, there are also stabilization systems using Shape Memory Alloy actuator mechanism and piezoelectric motors [7, 8]. Previously developed stabilization systems provide good results and can reduce the influence of vibrations on the camera optic, thereby improving the image quality of the camera. However, a stabilization system that can move automatically on the camera optic mechanism has never been developed and applied to CNC. Unlike the mechanism on the camera, the stabilization system on the CNC is applied to its head. In that way it will increase the stability and resistance of the CNC to vibration so as to increase the accuracy and quality of the processed product.

CNC requires a stability mechanism that can not only withstand vibration but also can provide good results when processing products with uneven surfaces. To be able to achieve the intended stability, a mechanism that can move freely or has several degrees of freedom (DOF) is needed. It is known that there is a mechanism, called the Stewart platform that has the ability to move freely up to 6 DOFs. Stewart platform can move rotationally and translationally relating to 3 axes: X, Y, and Z [9]. With such capabilities, if the Stewart platform can be controlled properly, this mechanism can solve the problems found in CNC. Research on the Stewart platform has been carried out and applied to various types of fields. The results showed that the Stewart platform is able to provide the movement with a high level of accuracy [10–12]. Other research results show that the Stewart platform is able to provide stability and is effective in reducing the vibrations generated [13]. Therefore, based on previous research, if the Stewart platform is applied to CNC, it will increase the accuracy and stability of the vibration generated, so it will improve the quality of the processed products. However, the Stewart platform with 6 DOFs is less effective to be applied to a CNC mechanism that only moves on 2 axes (X and Y) and only requires 3 DOFs of movement from the Stewart platform, namely rotational on the X and Y axes and translational on the Z axis. Stewart platform that only has 3 DOFs are referred to as Modified Stewart platform. The Modified Stewart platform has the same working principle as the regular Stewart platform, except that the DOF movement is limited. The Modified Stewart platform has the advantage of providing simplicity and convenience in its control system [14].

Before being applied to the CNC, it is necessary to conduct further research on the mechanism of the Modified Stewart platform. Therefore, the Modified Stewart platform is the object of this research. Several experiments were conducted to determine the accuracy and stability of the Modified Stewart platform. In this research, a mock-up or prototype and a simulation model of the Modified Stewart platform was developed. Furthermore, experiments were conducted on the mock-up and simulation model using the same parameters. The experimental data between the mock-up and simulation model will be compared and analyzed so that the Modified Stewart platform can be further evaluated. The results of the evaluation can be used to show the performance and development and improvement of the Modified Stewart platform so that later the Modified Stewart platform can be applied and improve the stability and accuracy of the CNC.

Modified Stewart platform

The Stewart platform is a manipulator device used to control position and movement. The Stewart platform consists of 2 fixed parts, the base and the platform. In addition, there are 6 legs that can be controlled in length. Originally, the Stewart platform was intended for the creation of flight simulators [15]. The Stewart platform mechanism consists of a triangular platform supported by ball joints and adjustable legs. With this mechanism, the Stewart platform has 6 DOFs. The advantage of the 6 DOFs Stewart platform is high accuracy and the ability to move easily at any desired angle and position. Therefore, Stewart platforms are widely used in structures with robotic applications such as the National Advance Driving Simulator. The angular displacement of the Stewart platform is greatly influenced by the length of the platform legs. However, the length of the platform legs also affects the length of the other legs [16]. The following figure is the scheme of the Stewart platform, Modified Stewart platform, and Design 3D of the Mock-up Modified Stewart platform (Fig. 1).

The Modified Stewart platform is an Original Stewart platform that has been modified. The Modified Stewart platform has only 4 legs, so this results in the Modified Stewart platform being able to move only in 3 DOFs. However, in general, the working principle of the Modified Stewart platform is the same as the Original Stewart platform. The movements of the Modified Stewart platform include rotating around the X and Y axes and translating along the Z axis. This is because the Modified Stewart platform will be used on CNC. The following figure is a mock-up of the Modified Stewart platform used in this research, with 3 main parts, namely: platform, legs, and base (Fig. 2).

In the mock-up Modified Stewart platform, there are several electronic components used to support its movement and mechanism, namely linear motor and Gyroscope sensor. The linear motor is used to drive the legs of the Modified Stewart platform and the Gyroscope sensor is used to detect the tilt of the platform. In the development of the Modified Stewart platform, there are parameters that have been obtained mechanically. For more details, here are the parameters of the mock-up Modified Stewart platform that has been developed (Table 1).

The linear motor movement is controlled using input steps where the legs of the Modified Stewart platform will increase in length by 0.002815 mm every 1 step. The

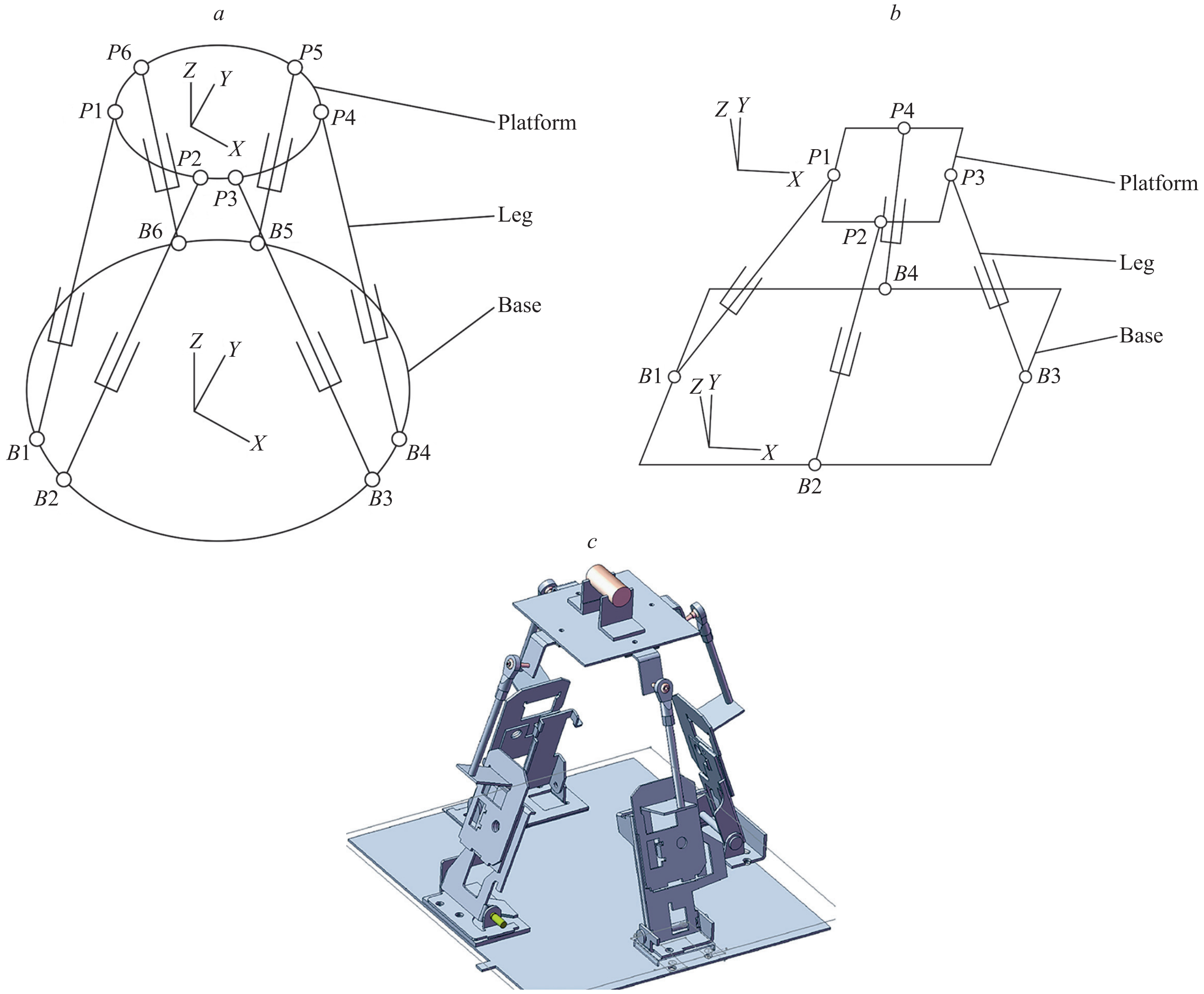

Fig. 1. Scheme of: Stewart platform (*a*); Modified Stewart platform (*b*); design 3D of mock-up Modified Stewart platform (*c*). *P*1 – *P*6 is joint section in the platform, *B*1 – *B*6 is joint section in the base

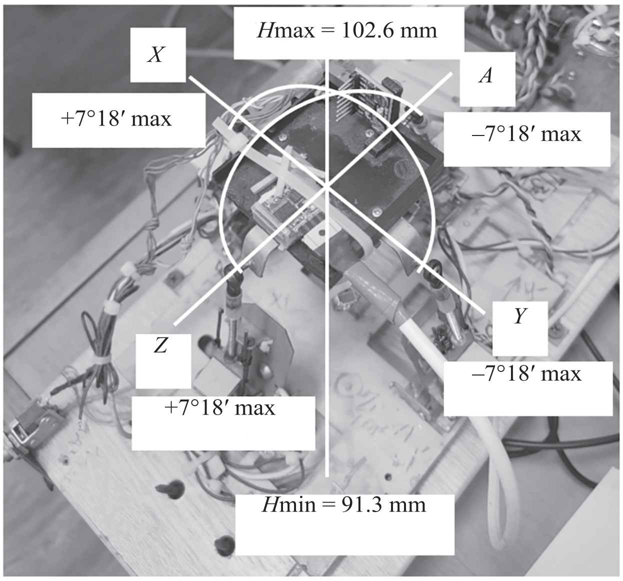

Fig. 2. Mock-up Modified Stewart platform. *X*, *Y*, *Z*, *A*: coordinates of the Modified Stewart platform with the angular rotation; *H*min and *H*max: the height of the Modified Stewart platform with translational movement

Table 1. Mock-up Modified Stewart platform parameters

Parameter	Value
Max steps	4000
Steps per, mm	0.002815
Height Maximum, mm	102.6
Height Minimum, mm	91.3
Base Length, mm	117.3
Platform Length, mm	88.6

parameters of the Modified Stewart platform will also be used as parameters of the simulation model. The platform can rotate by a maximum of 7°18′ on the *X* and *Y* axes. In the *Z* axis, the platform can move translationally by maximum of 11.3 mm.

Mathematical model of Modified Stewart platform

To be able to make a simulation of a system, a mathematical model is needed. A mathematical model is obtained from the mechanical design and electronic system parameters of the mock-up Modified Stewart platform. The mathematical model in this study is to find the platform position or angle. To simplify the calculation, the Modified Stewart platform is depicted in the form of a trapezoid. The following figure is a trapezoid used in the modeling of the mock-up platform (Fig. 3).

The *DC* and *AB* sides of the trapezoid always have the same size (constant). Increasing the lengths on the *AD* and *BC* sides is called delta (Δ). Delta greatly affects the angle of the trapezoid. The angle on the trapezoid is called theta (Θ). In addition to the slope of the trapezoid, the delta or the increasing of length *BC* and *AD* sides will affect the lengths of the *c* side. It is because the more inclined the trapezoid or platform, the longer the *c* side will be. The mathematical model of the modified Stewart platform can be described as follows.

To determine *BC* and *AD* sides, you can use the Pythagorean formula as follows:

$$BC^2 = (H + \Delta)^2 + (c + \Lambda)^2,$$
$$AD^2 = (H - \Delta)^2 + (c + \Lambda)^2.$$

Let us determine the height (*H*) of the trapezoid if the lengths of sides *BC* and *AD* are known.

$$H = \frac{\sqrt{(AD^2 - (c + \Lambda)^2)} + \sqrt{(BC^2 - (c + \Lambda)^2)}}{2}.$$

Let us now determine the angle of inclination of the platform or trapezoid Θ, then use the cosine formula. It is because the *BC* and *AD* sides have different lengths causing the platform to rotate at a fixed point. The rotation of the platform moves in the form of a circle, so determine the angle of inclination using the cosine formula. The derivation of the cosine formula from Fig. 3 of the platform is explained in the equation below:

$$\Delta^2 = \left(\frac{DC}{2}\right)^2 + (hO)^2 - 2\cos\Theta\left(\frac{DC}{2}\right)(hO).$$

To obtain *hO*, we use the following formula:

$$hO = \frac{AB - 2(c + \Lambda)}{2}.$$

So, to get the angle of the platform, we use the following equation:

$$\Theta = \arccos\left(\frac{\left(\frac{DC}{2}\right)^2 + \left(\frac{AB - 2(c + \Lambda)}{2}\right)^2 - \Delta^2}{2\left(\frac{DC}{2}\right)\left(\frac{AB - 2(c + \Lambda)}{2}\right)}\right).$$

From the equation, the inclination of the platform can be determined based on the lengths of the *BC* and *AD* sides of the trapezoid. The equation is used to create a simulation of the modified Stewart platform. The results of the angle in the simulation will be compared with the result of the angle on the mock-up Modified Stewart platform.

Simulation of Modified Stewart platform

The simulation is carried out on MATLAB which aims to be able to easily calculate and determine the angle of inclination of the platform based on the length of *BC* and *AD* sides of the trapezoid. Like on the mock-up Modified Stewart platform, input on the simulation is a signal (steps). In addition, to be able to make a simulation, it requires a reference height from the platform. In the simulation, the reference height is 97 mm. Like the mathematical model described previously, the Modified Stewart platform is calculated in the form of a trapezoid. The trapezoidal parameter used in the simulation corresponds to the parameters on the mock-up Modified Stewart platform. The following figure is a simulation program and interface of the Modified Stewart platform (Fig. 4).

The simulation can provide information about the angle of inclination, height, length of *BC* and *AD* sides, and the relative length of *Bg* and *Ae* sides. All this information is

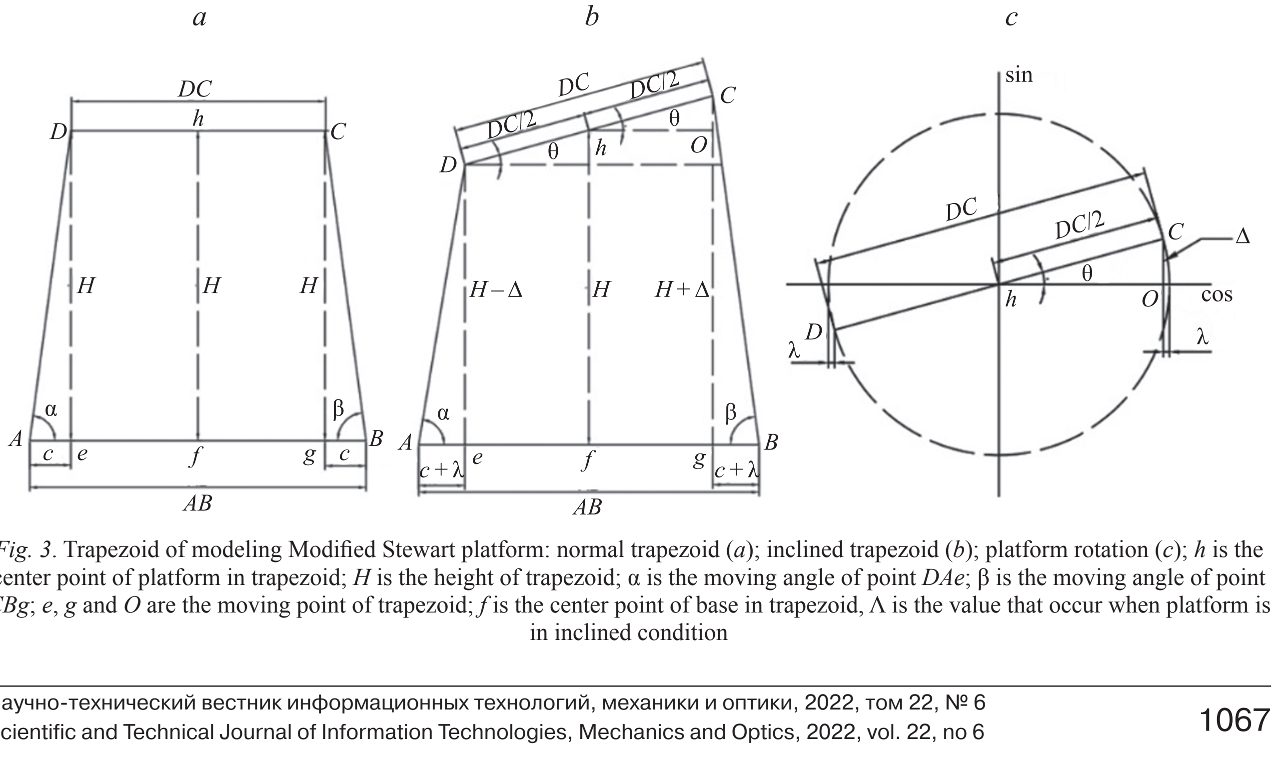
a *b* *c*

Fig. 3. Trapezoid of modeling Modified Stewart platform: normal trapezoid (*a*); inclined trapezoid (*b*); platform rotation (*c*); *h* is the center point of platform in trapezoid; *H* is the height of trapezoid; α is the moving angle of point *DAe*; β is the moving angle of point *CBg*; *e*, *g* and *O* are the moving point of trapezoid; *f* is the center point of base in trapezoid, Λ is the value that occur when platform is in inclined condition

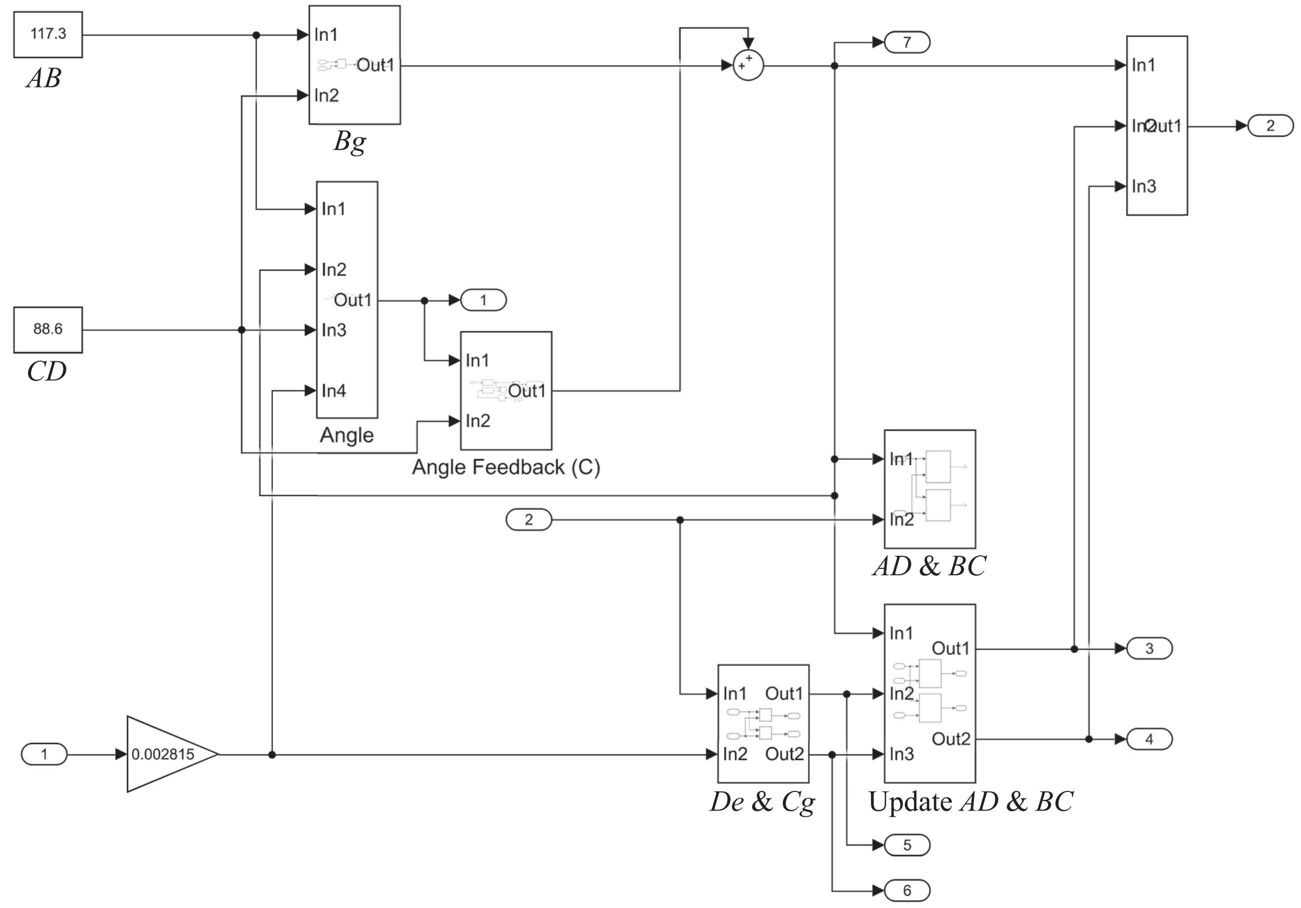

Fig. 4. Simulation program of Modified Stewart platform

obtained only by providing input in the form of steps. The simulation process was obtained from the mathematical model of the Modified Stewart platform that was carried out previously.

Now verify the results of the simulation, it can be done by comparing it with the trapezoid drawing in CAD. If there is an error in the calculation of the angle in simulation, the angle in CAD will give a different result. Simulations are used to verify the results of the mock-up Modified Stewart platform. Without simulation, it is difficult to determine the success of the working process of the mock-up Modified Stewart platform. The simulation also aims to get a more accurate value and can be used as a reference parameter to develop the Modified Stewart platform.

Evaluation of positioning error on Modified Stewart platform

The experiment aims to determine the position error on the Modified Stewart platform by comparing the platform angular position data to the platform simulation model. To be able to determine the position error on the platform, there are several conditions specified in this experiment. The data to be compared is the inclination angle of the platform in the *Z–A* plane. The input of the simulation and mock-up platform is the steps, starting from 0–2000 steps. The reference height on the platform with simulation is 97 mm. In the experiment, to determine the level of position error, the variable that is changed is not only the movement of steps but also the angle of the *X–Y* plane. The value of the experimental *X–Y* angle is 0°; 3°24′; 4°12′; 5°48′. By changing the angle contained in the *X–Y* plane, it can be seen the effect of the *X–Y* angle on the position error or angle of the *Z–A* plane. The following figure is a graph of the evaluation result between the mock-up and simulation of the Modified Stewart platform with an *X–Y* plane (Fig. 5).

From the experiments that have been conducted, it is known that the position or angle error of the *Z–A* plane is strongly influenced by changes in the angle of the *X–Y* plane. The platform angle on the *Z–A* plane with an *X–Y* angle of 0° has good results, meaning that the *Z–A* angle of the platform is the same as the angle from the model simulation. There is no significant difference between the model and experiment data of the platform. The position error of the platform is only located at steps 1600, 1800, and 2000. Changing the *Z–A* angle relative *X–Y* by 3°24′ has slightly unfavourable results, meaning that there is an angle difference between the model data and the experiment platform obtained. There is a position error on the *Z–A* plane of the platform, but overall, the angle obtained by the *Z–A* platform has shown that the movement of the platform position is in accordance with the movement in the simulation model. This also applies to the position of the *Z–A* angle with respect to the *X–Y* angle of 4°12′ and 5°48′ and the position error of the angle is relatively constant and stable.

The position or angle error of the platform is caused by several factors, including mechanical factors. The Modified

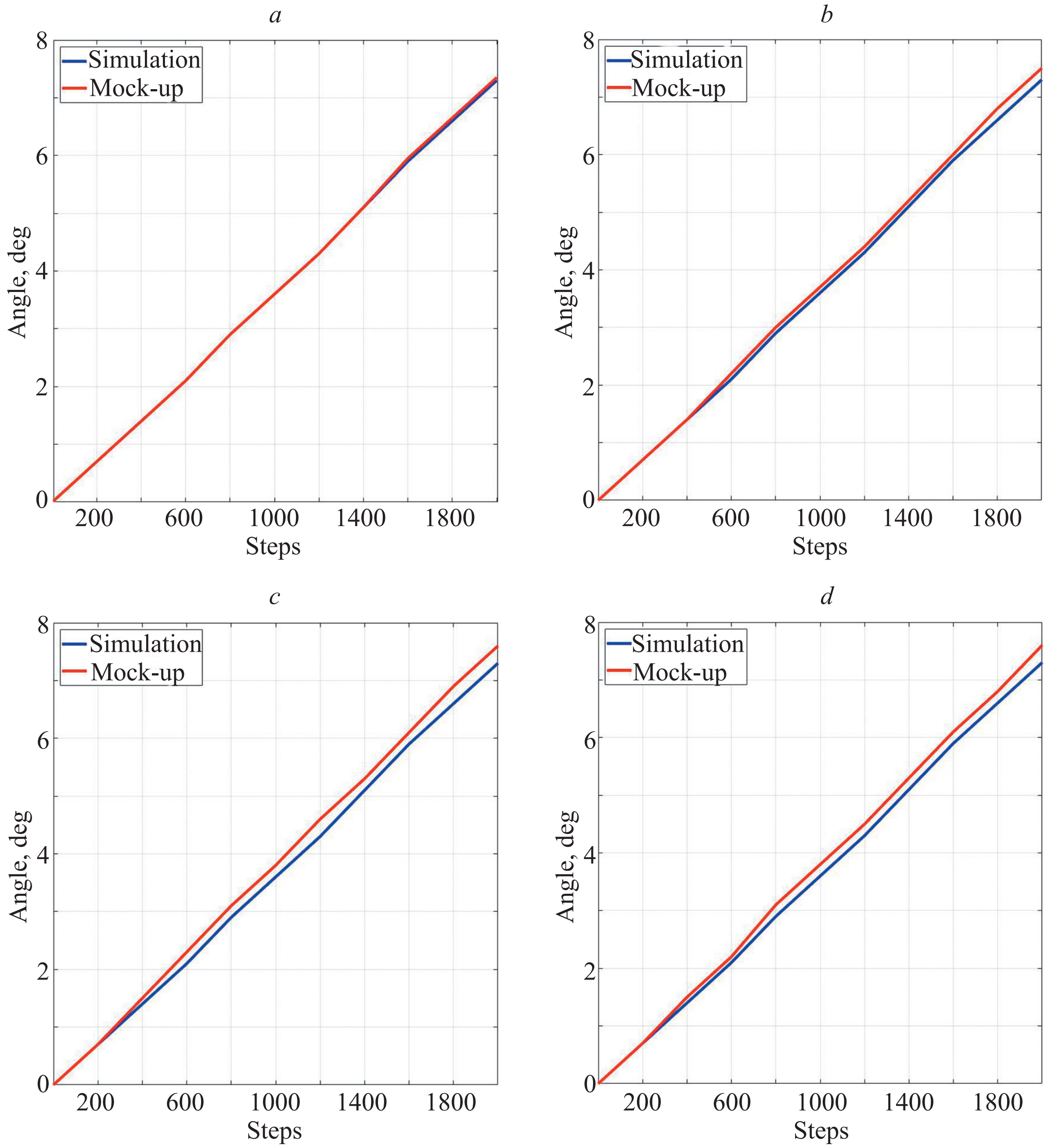

Fig. 5. Mock-up vs simulation of Modified Stewart platform with X–Y plane: 0° (*a*); 3°24′ (*b*); 4°12′ (*c*); 5°48′ (*d*)

Stewart platform has 3 DOFs that can rotate around the X–Y axes and is translational along the Z axis. To perform such movements, the Modified Stewart platform has a complex mechanism. The complex movement here means that the movement of one part affects the movement of other parts. On the other hand, this complex mechanism causes inaccuracies in the position or angle of the platform itself. The position error caused by the platform mechanism can be minimized by redesigning the platform and using components that can provide a much more precise movement, in addition to calculating the mechanical connections contained in the mechanical design of the platform.

In the experiment, it was found that the angular movements X–Y affected the position or angle of Z–A, causing a position or angle error. However, the simulation model does not allow taking into account the influence of the X–Y plane on the movement of the Z–A position. This can be possible if there is mechanical movement data of the platform or the influence of the X–Y plane on Z–A is known mathematically and is clear. However, it can be said in general that the movement generated by the platform is in accordance with the calculations and simulation models that have been developed. Admittedly, the movement of the platform is not perfect, but the error rate of the position or angle of the platform is small and it moves constantly.

The method of error compensation on the Modified Stewart platform

The Modified Stewart platform is a complex mechanism. This is obtained from the research results where one part will affect other parts. Based on the result of the research that has been done, to be able to compensate for errors on the Modified Stewart platform, it is carried out in the following method.

1. **Calibration.** Before working with the Modified Stewart platform, all movements regarding to the *X*, *Y*, and *Z* axes were confirmed to be in the correct position. In this research, the *X–Y* and *Z–A* planes were at a 0° angle. Calibration cannot be done on only one side, as the position error of either side will increase the position or angle error of the Modified Stewart platform.
2. **Data acquisition.** The data collected in this research on the Modified Stewart platform is angular. From the research that has been done, data acquisition cannot be done only once. It is necessary to collect data repeatedly, intending to see the level of stability of the movement of the platform. Due to its complexity, data acquisition must be done by applying many conditions and must be done regarding to both *X–Y* and *Z–A* planes. As shown in the research, data was collected on the *Z–A* plane with the *X–Y* plane located at angles of 0°; 3°24′; 4°12′; 5°48′. This needs to be done to determine the influence of the other side on the position or angle error of the platform.
3. **Mathematical modelling and simulation.** Modelling and simulation play an important role in determining the error compensation of the Modified Stewart platform. Simulation modelling acts as a reference and verifies the angular data provided by the Modified Stewart platform. Without the results of simulation modelling, it will be very difficult to determine the position error on the platform. However, it should be noted that the Modified Stewart platform has a complex mechanism, so modelling needs to be done with in-depth calculations such as kinematic calculations and so on.
4. **Data analysis.** After the data on the Modified Stewart platform and simulation are obtained, the next step is to analyze them. Both data are compared and observed, whether angular data from the Modified Stewart platform matches the simulation data. As in the research, repeated experiments are carried out and the trend of the data generated by the Modified Stewart platform is seen. Furthermore, the trend will be analyzed to determine the equation contained in the data. The equation will be used as a reference in developing the position control system of the Modified Stewart platform. By doing so, the position error on the platform can be reduced and the platform movement will be much more precise.
5. **Control system.** The control system is used to control the movement of the Modified Stewart platform. However, to develop the control system, equations obtained from previous experimental data are required. A good control system will provide a platform movement that matches the modelling and simulation. Also, the control system will reduce position error and increase the accuracy of the Modified Stewart platform.

Conclusion

The Modified Stewart platform is a device or platform that can move rotationally around the *X* and *Y* axes and translationally along the *Z* axis, in other words, it has 3 DOFs. This platform was developed to be applied to CNC to improve the accuracy and stability of the CNC head. A mock-up of the Modified Stewart platform has been developed and has been determined in accordance with the planned mechanical design. In addition, the mathematical model of the platform has been developed to determine the position or angle movement of the platform.

To determine the position or angle error of the Modified Stewart platform, an experiment was conducted by comparing the simulation model with the mock-up of the Modified Stewart platform. Several conditions were determined to identify the position error on the platform. In this research, it was found that the position or angle movement of the platform was following the calculation or simulation model. The movement of the Modified Stewart platform is so complex that the movement of one part also affects the movement of other parts. This causes position or angle errors to occur on the platform. The movement mechanism of the Modified Stewart platform needs to be considered and taken into account to minimize the position or angle error in its movement. A position error compensation method has also been developed, with the aim that it can later be used to evaluate complex mechanisms, such as the Modified Stewart platform, which can have high accuracy and stable movement that can be applied to CNC.

References

1. Shih M.-H., Sung W.-P., Chen C.-L. Vibration control and shock absorption techniques for Hi-Tech manufacturing plants. *Structural Design of Tall and Special Buildings*, 2012, vol. 21, no. 7, pp. 505–523. https://doi.org/10.1002/tal.625
2. Al-Shayea A., Abdullah F.M., Noman M.A., Kaid H., Abouel Nasr E. Studying and optimizing the effect of process parameters on machining vibration in turning process of AISI 1040 steel. *Advances in Materials Science and Engineering*, 2020, vol. 2020, pp. 5480614. https://doi.org/10.1155/2020/5480614
3. Chang C.-C., Hsia S.-Y., Huang H.-D. Improvement on CNC drilling quality using vibration suppression fixture. *Proc. of the 4th IEEE International Conference on Applied System Innovation (ICASI)*, 2018, pp. 910–913. https://doi.org/10.1109/ICASI.2018.8394415

Литература

1. Shih M.-H., Sung W.-P., Chen C.-L. Vibration control and shock absorption techniques for Hi-Tech manufacturing plants // Structural Design of Tall and Special Buildings. 2012. V. 21. N 7. P. 505–523. https://doi.org/10.1002/tal.625
2. Al-Shayea A., Abdullah F.M., Noman M.A., Kaid H., Abouel Nasr E. Studying and optimizing the effect of process parameters on machining vibration in turning process of AISI 1040 steel // Advances in Materials Science and Engineering. 2020. V. 2020. P. 5480614. https://doi.org/10.1155/2020/5480614
3. Chang C.-C., Hsia S.-Y., Huang H.-D. Improvement on CNC drilling quality using vibration suppression fixture // Proc. of the 4th IEEE International Conference on Applied System Innovation (ICASI). 2018. P. 910–913. https://doi.org/10.1109/ICASI.2018.8394415

4. Wang H., Huang Z., Wang C. Design of vibration test system for CNC milling machine. *ACM International Conference Proceeding Series*, 2020, pp. 279–284. https://doi.org/10.1145/3436286.3436406
5. Qiu C., Chen X., Hui Y., Siddiquee T.A.R. Study of dynamic vibration characteristics and suppression of CNC machine tool during operation. *Journal of Vibroengineering*, 2020, vol. 22, no. 8, pp. 1884–1895. https://doi.org/10.21595/jve.2020.21630
6. Song M.-G., Baek H.-W., Park N.-C., Park K.-S., Yoon T., Park Y.-P., Lim S.-C. Development of small sized actuator with compliant mechanism for optical image stabilization. *IEEE Transactions on Magnetics*, 2010, vol. 46, no. 6, pp. 2369–2372. https://doi.org/10.1109/TMAG.2010.2042288
7. Kazi A., Honold M., Rimkus W., Lokner T., Bäuml M., Köpfer M. SMA actuator for optical image stabilization. *ACTUATOR 2018 — 16th International Conference and Exhibition on New Actuators and Drive Systems, Conference Proceedings*, 2018, pp. 375–378.
8. Karev P.V. Optical stabilization and microscanning with piezo actuators and piezoelectric motors. *Proc. of the International Conference Laser Optics 2018 (ICLO)*, 2018, pp. 192. https://doi.org/10.1109/LO.2018.8435895
9. Dasgupta B., Mruthyunjaya T.S. Stewart platform manipulator: A review. *Mechanism and Machine Theory*, 2000, vol. 35, no. 1, pp. 15–40. https://doi.org/10.1016/S0094-114X(99)00006-3
10. Yufei X., He L., Yanbin Z., Fei X., Jing Z. Dynamic modeling and high accuracy attitude control of a Stewart spacecraft. *Proc. of the 29th Chinese Control and Decision Conference (CCDC)*, 2017, pp. 7395–7400. https://doi.org/10.1109/CCDC.2017.7978522
11. Noskievic P., Walica D. Design and realisation of the simulation model of the Stewart platform using the MATLAB-Simulink and the Simscape Multibody library. *Proc. of the 21st IEEE International Carpathian Control Conference (ICCC)*, 2020, pp. 9257249. https://doi.org/10.1109/ICCC49264.2020.9257249
12. McCann C., Patel V., Dollar A. The Stewart hand: A highly dexterous, six-degrees-of-freedom manipulator based on the stewart-gough platform. *IEEE Robotics and Automation Magazine*, 2021, vol. 28, no. 2, pp. 23–36. https://doi.org/10.1109/MRA.2021.3064750
13. Bi F., Ma T., Wang X., Yang X., Lv Z. Research on vibration control of seating system platform based on the cubic stewart parallel mechanism. *IEEE Access*, 2019, vol. 7, pp. 155637–155649. https://doi.org/10.1109/ACCESS.2019.2948785
14. Fedosov Y.V., Afanasev M.Y. Design of an adaptive system for stabilization of a laser beam for CNC machine. *Proc. of the 19th Conference of Open Innovation Association, FRUCT*, 2017, pp. 31–36. https://doi.org/10.23919/FRUCT.2016.7892180
15. Guo H.B., Li H.R. Dynamic analysis and simulation of a six degree of freedom Stewart platform manipulator. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, 2006, vol. 220, no. 1, pp. 61–72. https://doi.org/10.1243/095440605X32075
16. Şumnu A., Güzelbey İ.H., Çakir M.V. Simulation and PID control of a Stewart platform with linear motor. *Journal of Mechanical Science and Technology*, 2017, vol. 31, no. 1, pp. 345–356. https://doi.org/10.1007/s12206-016-1238-7

4. Wang H., Huang Z., Wang C. Design of vibration test system for CNC milling machine // ACM International Conference Proceeding Series. 2020. P. 279–284. https://doi.org/10.1145/3436286.3436406
5. Qiu C., Chen X., Hui Y., Siddiquee T.A.R. Study of dynamic vibration characteristics and suppression of CNC machine tool during operation // Journal of Vibroengineering. 2020. V. 22. N 8. P. 1884–1895. https://doi.org/10.21595/jve.2020.21630
6. Song M.-G., Baek H.-W., Park N.-C., Park K.-S., Yoon T., Park Y.-P., Lim S.-C. Development of small sized actuator with compliant mechanism for optical image stabilization // IEEE Transactions on Magnetics. 2010. V. 46. N 6. P. 2369–2372. https://doi.org/10.1109/TMAG.2010.2042288
7. Kazi A., Honold M., Rimkus W., Lokner T., Bäuml M., Köpfer M. SMA actuator for optical image stabilization // ACTUATOR 2018 — 16th International Conference and Exhibition on New Actuators and Drive Systems, Conference Proceedings. 2018. P. 375–378.
8. Karev P.V. Optical stabilization and microscanning with piezo actuators and piezoelectric motors // Proc. of the International Conference Laser Optics 2018 (ICLO). 2018. P. 192. https://doi.org/10.1109/LO.2018.8435895
9. Dasgupta B., Mruthyunjaya T.S. Stewart platform manipulator: A review // Mechanism and Machine Theory. 2000. V. 35. N 1. P. 15–40. https://doi.org/10.1016/S0094-114X(99)00006-3
10. Yufei X., He L., Yanbin Z., Fei X., Jing Z. Dynamic modeling and high accuracy attitude control of a Stewart spacecraft // Proc. of the 29th Chinese Control and Decision Conference (CCDC). 2017. P. 7395–7400. https://doi.org/10.1109/CCDC.2017.7978522
11. Noskievic P., Walica D. Design and realisation of the simulation model of the Stewart platform using the MATLAB-Simulink and the Simscape Multibody library // Proc. of the 21st IEEE International Carpathian Control Conference (ICCC). 2020. P. 9257249. https://doi.org/10.1109/ICCC49264.2020.9257249
12. McCann C., Patel V., Dollar A. The Stewart hand: A highly dexterous, six-degrees-of-freedom manipulator based on the stewart-gough platform // IEEE Robotics and Automation Magazine. 2021. V. 28. N 2. P. 23–36. https://doi.org/10.1109/MRA.2021.3064750
13. Bi F., Ma T., Wang X., Yang X., Lv Z. Research on vibration control of seating system platform based on the cubic stewart parallel mechanism // IEEE Access. 2019. V. 7. P. 155637–155649. https://doi.org/10.1109/ACCESS.2019.2948785
14. Fedosov Y.V., Afanasev M.Y. Design of an adaptive system for stabilization of a laser beam for CNC machine // Proc. of the 19th Conference of Open Innovation Association, FRUCT. 2017. P. 31–36. https://doi.org/10.23919/FRUCT.2016.7892180
15. Guo H.B., Li H.R. Dynamic analysis and simulation of a six degree of freedom Stewart platform manipulator // Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science. 2006. V. 220. N 1. P. 61–72. https://doi.org/10.1243/095440605X32075
16. Şumnu A., Güzelbey İ.H., Çakir M.V. Simulation and PID control of a Stewart platform with linear motor // Journal of Mechanical Science and Technology. 2017. V. 31. N 1. P. 345–356. https://doi.org/10.1007/s12206-016-1238-7

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