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DYNAMIC ANALYSIS AND CONTROL OF MODULAR UNIVERSAL ROTARY WELDING DEVICE

Yuriy Kuznetsov*, Nazar Pidhornyi

National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kiev, Ukraine

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ABSTRACT

The article considers dynamic modeling and design features of a universal rotary welding device adapted to the needs of modern production. A modular construction principle is described, which allows to increase the functional flexibility and maintainability of the system. Based on the Lagrangian approach, the equations of motion for the rotary and tilting components of the mechanism are formulated, taking into account the action of external loads, damping forces and moments of inertia. Control options are analyzed, in particular the use of PID and adaptive controllers, which allow to ensure high positioning accuracy and reduce vibrations during operation..

1. INTRODUCTION

Rotational-rotating devices are technological equipment used for spatial manipulation of workpieces during welding. They provide rotation of parts both around the horizontal and vertical axes, and also allow changing their position by tilting them relative to the horizontal plane. This makes it possible to optimally position the weld in the most favorable position for performing welding operations, reducing the load on the operator and improving the quality of the seam [1].

These devices are usually structurally similar and provide for fixing the product using a faceplate, which can be equipped with both universal and specialized fastening elements. Despite the variety of models, all rotational-rotating devices are based on a single design principle, which assumes the presence of two main perpendicular axes: the axis of rotation and the axis of tilting. The first, which is responsible for the rotational movement of the faceplate, is implemented through the spindle of the device, while the second, perpendicular to the first, provides a tilt of the faceplate in the range from 90° to 135° [1, 2, 3].

The presence of a drive in the design of the device allows you to control the speed of rotation of the faceplate, which is critically important for maintaining the optimal welding mode, especially when forming circular seams. Additionally, many models provide the ability to switch between different speed modes, which allows you to use both working speeds for direct welding operations, and marching or setting modes for adjusting the position of the part before starting work.

Rotary devices are divided into two main categories depending on their functional purpose: universal manipulators of general application and specialized devices.

The purpose of the study is to analyze the dynamics of universally rotary welding devices (URWD) with a special emphasis on their use in the welding industry (Fig. 1-2).

Fig.1. Universal rotary welding device [4]

* Corresponding author. E-mail: info@zmok.kiev.ua

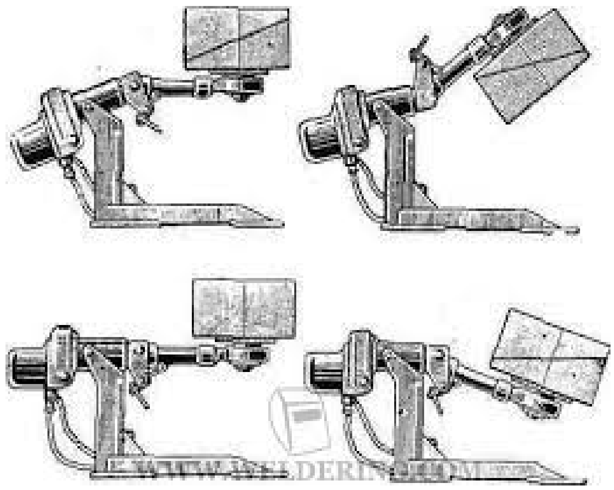

Fig. 2. Universal rotary welding device [5]

A universal swivel device can have two main degrees of freedom (Fig. 3):

1. Rotational movement around a horizontal axis. This is the movement that determines the angle of inclination of the part for the accessibility of the welding tool.

2. Rotational movement around a vertical axis. This is the movement that ensures uniform rotation of the part during the welding process.

Fig. 4 shows the layout of the URWD, which was presented in the article [7].

The kinematic equations for these movements can be presented in the form of Lagrange differential equations of the second kind [9, 10]:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right)-\left(\frac{\partial L}{\partial \dot{q}_i}\right)=Q_i$$

- $L=T-V$ — Lagrangian of the system, defined as the difference of kinetic T and potential V energies;
- q_i - generalized coordinates (angular displacements);
- Q_i - generalized external forces and moments.

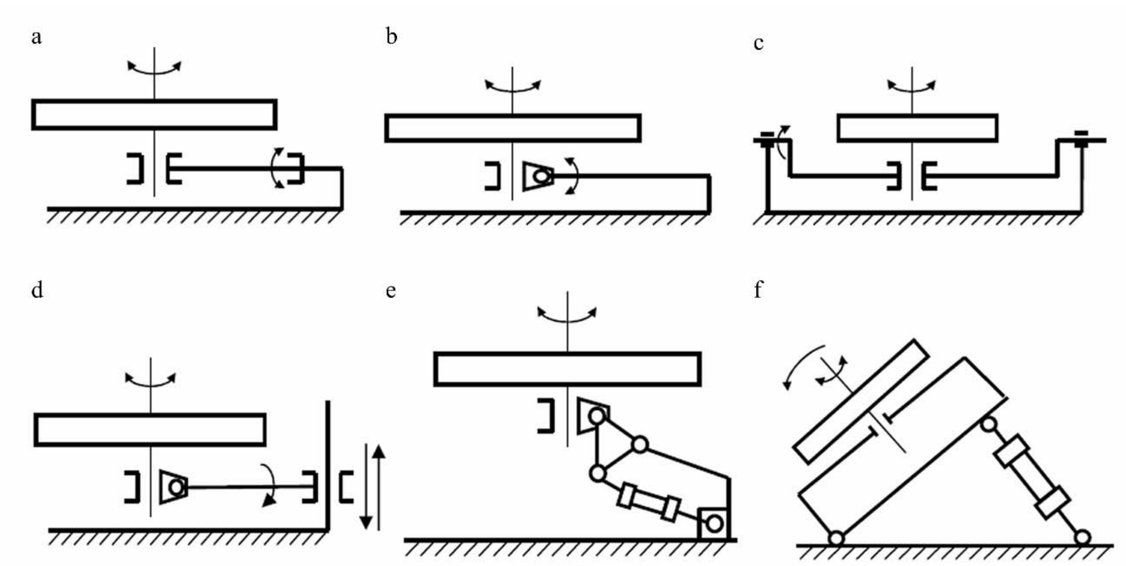

Fig. 3. Known structural schemes of Universal rotary welding device: a-cantilever; b-carousel; c-carousels with full, d-carousel with radial lift; e-lever-sector; f- carousels with full balancing relative to the tilt axis. [5, 6, 7]

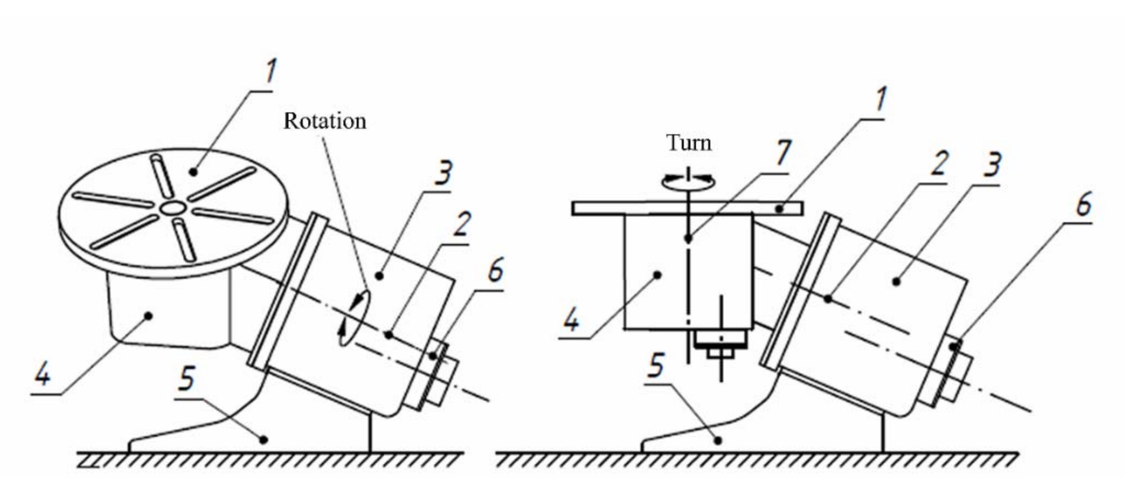

Fig. 4. Variant of the Universal rotary welding device layout

If we denote the angle of inclination of the platform as θ, and the angular position of the part relative to the vertical axis as ϕ, then the kinematic equations will have the form:

$$I_\theta\ddot{\theta}+C_\theta\dot{\theta}+M_\theta=T_\theta$$
$$I_\phi\ddot{\phi}+C_\phi\dot{\phi}+M_\phi=T_\phi$$

• I_{θ}, I_{ϕ} - moments of inertia about the corresponding axes;

• C_{θ}, C_{ϕ} - damping coefficients, depending on the viscosity of the material and the type of drive;

• M_{θ}, M_{ϕ} - moments from external loads;

• T_{θ}, T_{ϕ} - applied torques from the drives.

To assess the behavior of the device under variable loads, it is necessary to take into account the moments of inertia. The basic formula for calculating the moment of inertia about any axis is:

$$I = \int r^2 dm$$

• r - distance of the differential mass element dm from the axis of rotation.

Depending on the type of device, approximate values of the moments of inertia can be determined:

- for a disk-shaped platform:

$$I = \frac{1}{2} MR^2$$

- for a cylindrical welded product:

$$I = \frac{1}{2} M\left(R_1^2 + R_2^2\right)$$

R_1 and R_2 are the inner and outer radii. The force load of the device is determined by the dynamic equilibrium equation [9]:

$$F = ma$$

• F - is the force acting on the device;

• m - is the mass of the part;

• a - is the acceleration during movement.

Since the movement of the platform is rotational, a similar formula is used for torque:

$$M = I\alpha$$

• α — angular acceleration.

During the operation of the URWD, vibrations may occur, which negatively affect the accuracy of welding. The main causes of vibrations are: I - uneven mass of the part; II - sudden changes in speed of movement; III - the influence of the welding process (for example, thermal expansion of the metal) [1, 5, 9].

Vibrations can be described and investigated by the differential equation of the harmonic oscillator:

$$m\ddot{x} + c\dot{x} + kx = F(t)$$

x — displacement;

c — damping coefficient;

k — stiffness of the structure;

$F(t)$ — external disturbing force.

To avoid resonance phenomena, it is necessary to control the natural frequencies. To control them, the following formula can be used, which determines the frequency of free undamped vibrations of a mechanical system without taking into account external forces and damping:

$$\omega_0 = \sqrt{\frac{k}{I}}$$

Optimal control of the platform motion can be called the use of controllers that allow minimizing oscillations and improving positioning accuracy. The most common control method is the PID controller (proportional-integral-derivative control). It can be described by the PID law [10-12]:

$$T = K_p e + K_i \int e dt + K_d \frac{de}{dt}$$

• e — position error;

• K_p, K_i, K_d — controller coefficients.

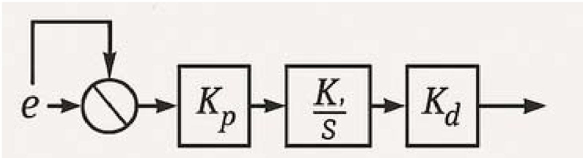

Fig.5. Structure of the OPP control system

Fig. 5 shows the structure of the rotary welding device control system, built on the basis of the PID controller. The system includes a proportional (P), integral (I) and differential (D) control unit, which together ensure the stability of the movement of the working platform and the correction of deviations from the specified parameters. The input signal is the specified position of the platform, and the output signal is the control action on the actuators. This allows you to minimize positioning errors and compensate for possible fluctuations that occur during operation. In addition, adaptive and fuzzy controllers can be used to improve the control of the URWD. For example, adaptive PID controllers change their coefficients depending on the dynamic characteristics of the device [10-12]:

$$K_p(t) = K_{p0} + \alpha_p e^2(t),$$

$$K_d(t) = K_{d0} + \alpha_d \frac{de^2(t)}{dt},$$

$$K_i(t) = K_{i0} + \alpha_i \int e^2(t) dt,$$

which allows to increase the stability of the system under conditions of variable loads.

Also, a parametric sensitivity analysis of the system is performed, which allows to assess the impact of changing parameters on the dynamic characteristics. It can be performed using the following formulas:

$$S_k = \frac{\partial \omega_0}{\partial k}, \quad S_I = \frac{\partial \omega_0}{\partial I}.$$

Analysis and optimization of these parameters allow to increase the accuracy of the URWD operation and reduce energy consumption.

CONCLUSIONS

The article presents a substantiated approach to the formalization of the principle of building a dynamic model of a universal rotary welding device taking into account its structural modularity. The main kinematic parameters and physical factors that have a critical impact on the dynamics of the device's functioning are determined, in particular, mass-inertial characteristics, external force actions and damping properties of mechanical connections.

The proposed calculation principle is based on the application of Lagrangian equations of the second kind, which allows in further research to build a complete mathematical model with the possibility of adapting it to specific device configurations and operating conditions. The paper also considers the feasibility of using classical and adaptive control algorithms to ensure accurate positioning of working elements, reduce vibration levels and increase stability of operation under external disturbances.

The results obtained have theoretical value for further modeling, development of control systems and design optimization of new generation welding devices that meet the requirements of modern production systems in the fields of mechanical engineering, defense industry and heavy welding production.

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