Perspectives in Science (2016) 7, 347—352

Available online at www.sciencedirect.com

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journal homepage: www.elsevier.com/pisc

Strength analysis and optimization of welding robot mechanism in emergency stop state☆

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Received 6 November 2015; accepted 23 November 2015
Available online 12 December 2015

KEYWORDS
Dynamical analysis;
Stress;
Excitation;
Response;
Mechanism

Summary The contribution deals with the strength analysis and optimization of the welding robot mechanism in emergency stop state. The common operational positioning of the welding robot is characterized by smooth course of speeds in the time. The resulting load does not differ significantly from the static loading. However the safety requirements given by the norm require the ability of emergency stop function. Since the course of speed in time is rather steep the higher values of acceleration and thus higher excitation force is expected. The dynamical simulation performed describes the response of the robot mechanism in the form of stress course in time, quantifies the peak values of the stress caused by the dynamical component of loading and highlights the potential risks associated with this phenomenon.

Introduction

THE subject of the work is the welding robot mechanism. The mechanism is consisting of three sliders which ensure the positioning of the welding device in any directions. The welding device itself is mounted to the upper horizontal slider.

The welding procedure is divided into two steps. Firstly, the positioning of the welding device is realized by translational motion of all three sliders in three directions. Secondly, the welding process is performed while the sliders remain still.

☆ This article is part of a special issue entitled ''Proceedings of the 1st Czech-China Scientific Conference 2015''.

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http://dx.doi.org/10.1016/j.pisc.2015.11.053

Nomenclature

F	force, N
F_0	excitation force, N
t	time, s
m	mass, kg
b	damping coefficient, kg/s
k	stiffness, N/m
$x, \dot{x} = v, \ddot{x} = \dot{v} = a$	deflection, speed, acceleration, m, m s^{-1}, m s^{-2}
$z, \dot{z} = v_z, \ddot{z} = \dot{v}_z = a_z$	deflection, speed, acceleration in substitution, m, m s^{-1}, m s^{-2}
A, B, C, φ_0	integration constants, m, m, m, −
x_{stat}	static deflection, m
δ	decay constant, 1/s
Ω_0	natural frequency (undamped), 1/s
Ω	natural frequency (damped), 1/s
T	vibration period, s
v_{0_LHS}	initial speed (common operational) of the lower horizontal slider, m s^{-1}
a_{LHS}	deceleration (emergency value) of the lower horizontal slider, m s^{-2}
v_{0_VS}	initial speed of vertical slider, m s^{-1}
v_{0_UHS}	initial speed of upper horizontal slider, m s^{-1}
g	gravitational acceleration, m s^{-2}
f_y	yield stress, Pa

The time change of speed of all three sliders during the positioning before welding is very smooth so the acceleration of all movable parts is very low. Based on this fact the minimal increment of loading due to the dynamical forces can be expected and methods of statics could be used for the design of the mechanism.

As already mentioned above the common operational state (i.e. positioning of the sliders) of the robot does not cause higher dynamical loading. The opposite is the case when the device is suddenly stopped due to the emergency stop function. Emergency stop function serves for the immediate stopping of all motions in case of any danger, e.g. obstacle in the motion trajectory, sudden power outage etc. Parameters of the emergency stop state are usually defined by the norm and require actions in very short time periods which can cause high accelerations and forces of all related parts and consequently significant influence on the stress state in the mechanism body. This influence and its consequences will be presented on the emergency stop during the positioning of the lower horizontal slider of the welding robot.

Theoretical background

Dynamic properties of the vibrating system can be evaluated based on its response on the step change of the excitation force (Ondrouch and Podesva, 2012) — see Fig. 1. During this step change the external force F suddenly reaches the non-zero value and this value is further hold at the constant level. The response of the vibrating system is called the step response.

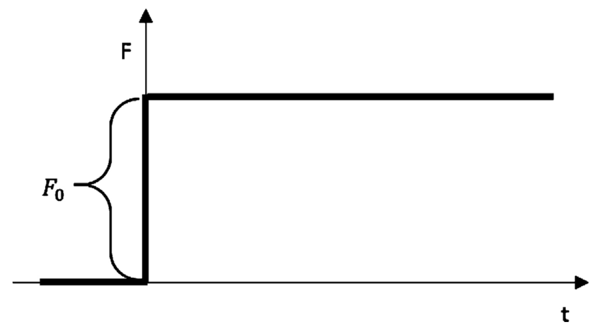

Figure 1 Step change of the excitation force.

The equation of motion of the system is

$$m\ddot{x} + b\dot{x} + kx = F_0 \tag{1}$$

or

$$\ddot{x} + 2\delta\dot{x} + \Omega_0^2 x = \frac{F_0}{m} \tag{2}$$

respectively.

Let us lead in the following substitution

$$z = x - x_{stat} \quad \dot{z} = \dot{x} \quad \ddot{z} = \ddot{x} \tag{3}$$

The equation of motion reaches then the following shape

$$m\ddot{z} + b\dot{z} + k(z + x_{stat}) = F_0 \tag{4}$$

$$m\ddot{z} + b\dot{z} + kz + k\frac{F_0}{k} = F_0 \tag{5}$$

and finally

$$m\ddot{z} + b\dot{z} + kz = 0 \tag{6}$$

The solution of the last differential equation can be written as follows

$$z(t) = Ce^{-\delta t}\sin(\Omega t + \varphi_0) \tag{7}$$

Using the substitution mentioned above we obtain

$$x(t) = x_{stat} + Ce^{-\delta t}\sin(\Omega t + \varphi_0) \tag{8}$$

$$x(t) = x_{stat} + e^{-\delta t}[A\cos(\Omega t) + B\sin(\Omega t)] \tag{9}$$

$$\dot{x}(t) = v = e^{-\delta t}[(B\Omega - A\delta)\cos(\Omega t) - (A\Omega + B\delta)\sin(\Omega t)] \tag{10}$$

Integration constants A and B or C and φ_0 can be calculated from initial conditions corresponding to the resting initial state

$$t = 0 \ldots x(t = 0) = x_0 = 0, \quad v(t = 0) = v_0 = 0 \tag{11}$$

Solution of Eqs. (1) or (2) respectively is then

$$x(t) = x_{stat}\left\{1 - e^{-\delta t}\left[\cos(\Omega t) + \frac{\delta}{\Omega}\sin(\Omega t)\right]\right\} \tag{12}$$

This function is called step response. Its graph is depicted in Fig. 2.

The course of the system response stabilizes after the initial excitation at the value $x = x_{stat}$. However, at the beginning before the vibration stabilizes, the deflections can reach even the value $x = 2x_{stat}$.