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Harmonic Analysis in the Power Supply System of a Selected Single-Phase Industrial Robot

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Abstract

The selection of industrial robots in technological lines is primarily based on their technical characteristics, such as the type of construction, the number of axes, reach, maximum load, and power supply parameters (power consumption in single-phase or three-phase systems). In the overall energy balance, the transient states and the harmonics of voltages and currents in the power supply system of the selected industrial robot are also operationally significant. The article presents the results of the harmonic analysis of voltage and current in the power supply system of a chosen industrial single-phase robot.

Keywords:

harmonic analysis, FFT, industrial robot, robot power supply system, electrical power quality

1. INTRODUCTION

Industrial robots are widely used to perform various automated tasks. In the foundry industry they can, among other things, transport casting cores or castings. Moving multiple casting components during a single cycle robot means the gripper will cover a total path length in a certain amount of time. Measurements carried out in a laboratory equipped with a Fanuc LR Mate 200iD/4S robot [1] (Fig. 1) have shown that the routes determined by the various algorithms have different total lengths and cycle times of the multi-component transport program.

This is also related to the varying power consumption of the robot controller, hence it was reasonable to investigate the dynamics of changes in the values of energy parameters in its power system.

This can be realized, among other things, by recording the instantaneous values of voltages and currents in the power system and performing the necessary numerical calculations.

This paper will present the results of an analysis of voltage and current harmonics in the power system of a selected single-phase industrial robot.

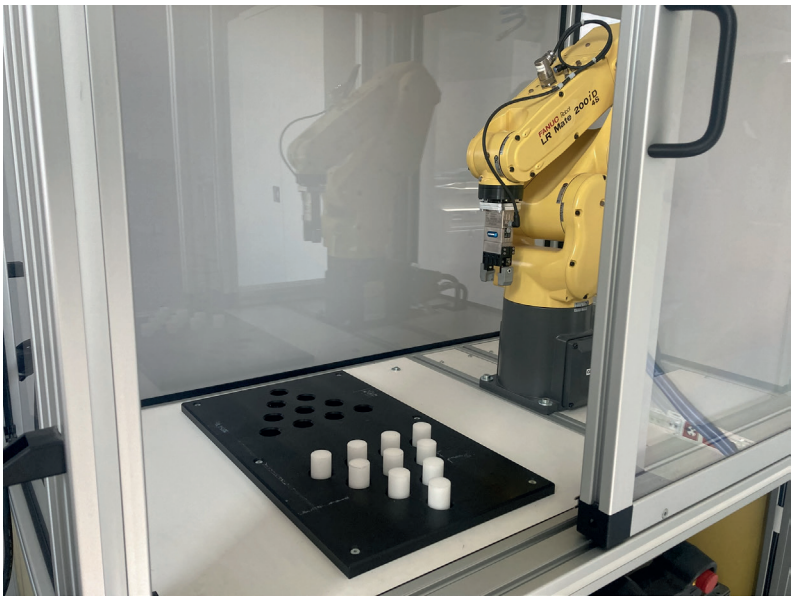
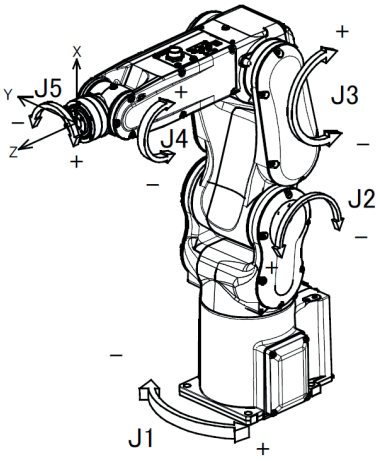


Fig. 1. View of laboratory station with the Fanuc's LR Mate 200iD/4S robot

2. DESCRIPTION OF THE APPROACH

The LR Mate 200iD/4S 6-axis industrial robot is controlled by an R30-iB Plus controller [2] from a single-phase power supply. Figure 2 shows the short names of the individual axes and their corresponding rotation angle ranges and maximum rotational speeds [3].



Axis	Motion range, °	Max. speed, °/s
J1	340	460
J2	230	460
J3	402	520
J4	380	560
J5	240	560
J6	720	900

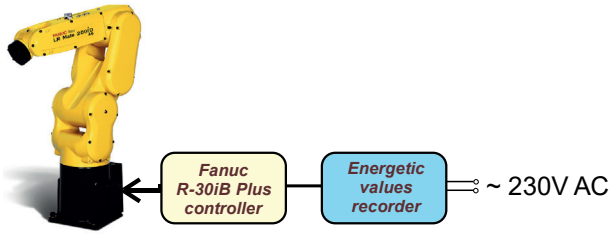
Fig. 2. Position of each axis, motion range and maximum speed of the LR Mate 200*i*D/4S robot [2, 3]

The tested robot was programmed to perform the following movements:

- return to the HOME position,
- 3 consecutive rotations of each axis at a rotational speed equal to 20% of the maximum speed.

Three variants of robot arm load were assumed: 250 g, 1500 g and 3000 g, for which measurements were carried out by recording instantaneous voltage and current values in a single-phase power supply system from the power grid using a microprocessor system developed by the author (Fig. 3).

a)



b)

Fig. 3. Measurement schema (a) and view of the instantaneous voltage and current recorder (b) in the power supply system of the selected robot [4]

Recording is performed using voltage (LV 25-400) and current (LA 25-NP) transducers from LEM [5–7]. The system transmits values of 4000 voltage samples and 4000 current samples in 1 second via a USB interface to the computer's storage memory [4]. This allows for very precise recording of changes in the value and shape of voltage and current waveforms.

During all measurements, the supply voltage was recorded in the range from 228.5 V to 230.6 V.

Figure 4 shows the current RMS values in the power supply system of this robot during its operating cycle for different arm loads.

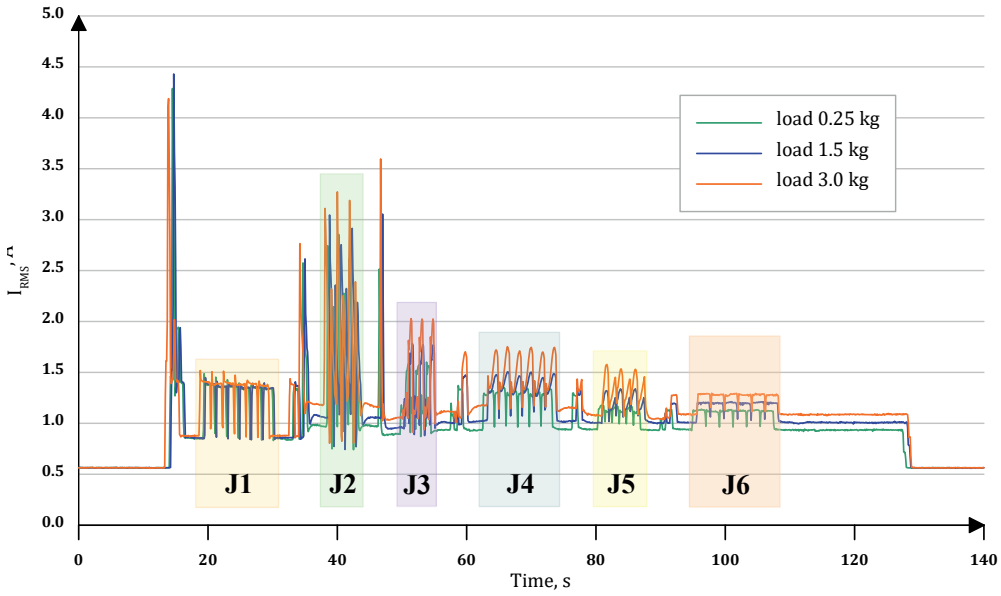


Fig. 4. Graph of the effective current value in the power supply system of the tested robot for different arm loads

3. VOLTAGE AND CURRENT HARMONICS ANALYSIS

A fast Fourier transform (FFT) algorithm was used to calculate numerically the amplitudes of the individual harmonics for the voltage and current waveforms [8, 9]. The measure of voltage harmonic distortion is the Total Harmonic Distortion of Voltage THD_U, which is calculated using the following formula:

$$THD_U = \frac{\sqrt{U_2^2 + U_3^2 + \ldots U_h^2}}{U_1} \cdot 100\% \quad (1)$$

while the measure of harmonic distortion of the current can be determined from the formula:

$$THD_I = \frac{\sqrt{I_2^2 + I_3^2 + \ldots I_h^2}}{I_1} \cdot 100\% \quad (2)$$

where:

$U_1, \ldots, U_h$ – amplitudes of individual voltage harmonics,
$I_1, \ldots, I_h$ – amplitudes of individual current harmonics,
h – number of harmonics considered.

In order to determine the amplitudes of the successive harmonics, the instantaneous values of the voltages and currents were recorded over the entire measurement range during the execution of the work cycle of the robot under test. For example, Figure 5 shows the voltage waveform (4096 samples in a time window of 1.024 s) of the robot power system, together with the flat-top window function and the resulting input value waveform for the FFT algorithm [8].

Figures 6–8 show (for axis J1, J2 and J3, respectively) graphs of changes effective current values and waveforms of instantaneous voltage and current values in selected time intervals for different loads on the arm of the tested robot.

The calculations of the percentage values of current odd harmonics for the assumed loads on the robot arm, performed using the FFT algorithm, are presented in the form of a graph in Figure 9.

The results of the FFT algorithm calculations of the maximum THD_U and THD_I values for each robot axis are presented in Table 1.

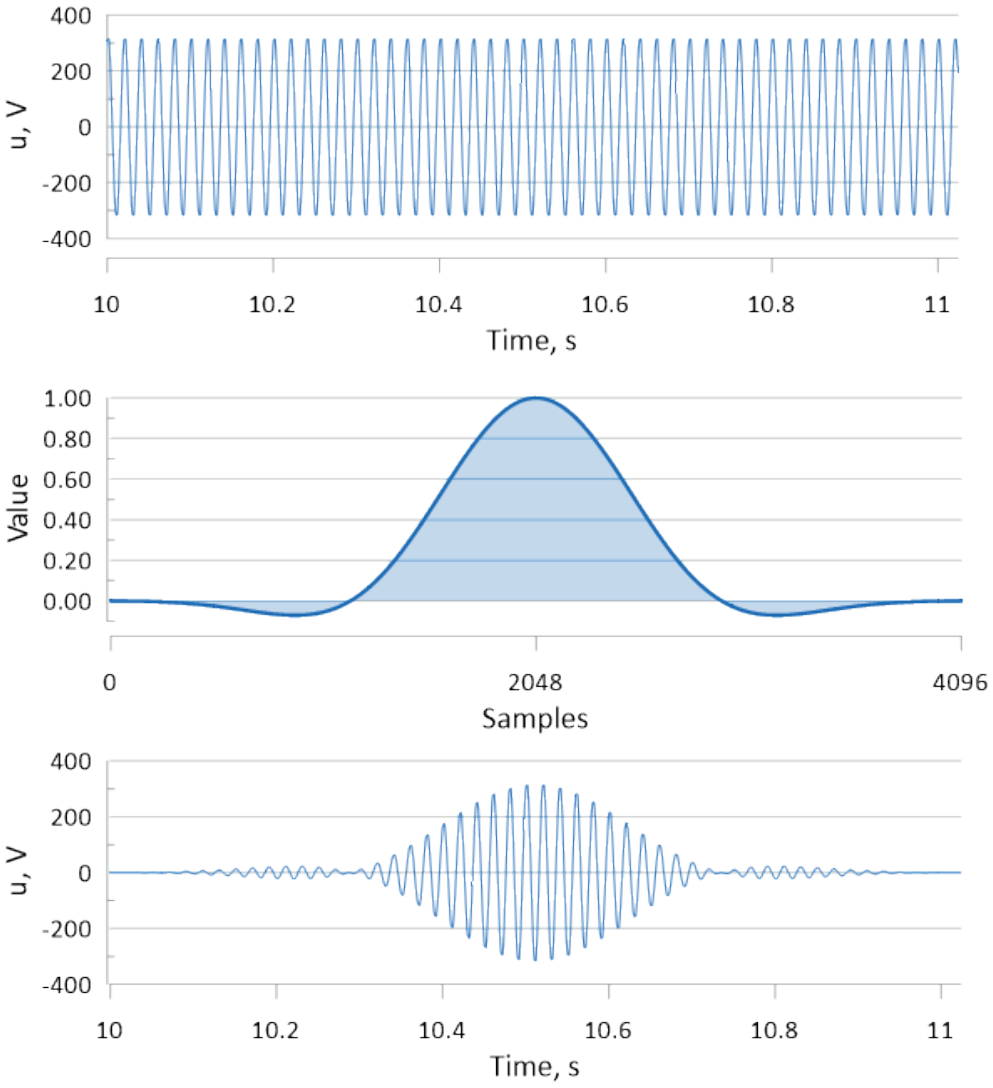


Fig. 5. The voltage waveform of the robot power system and the flat-top window function and input value plot for the FFT algorithm in the selected time window

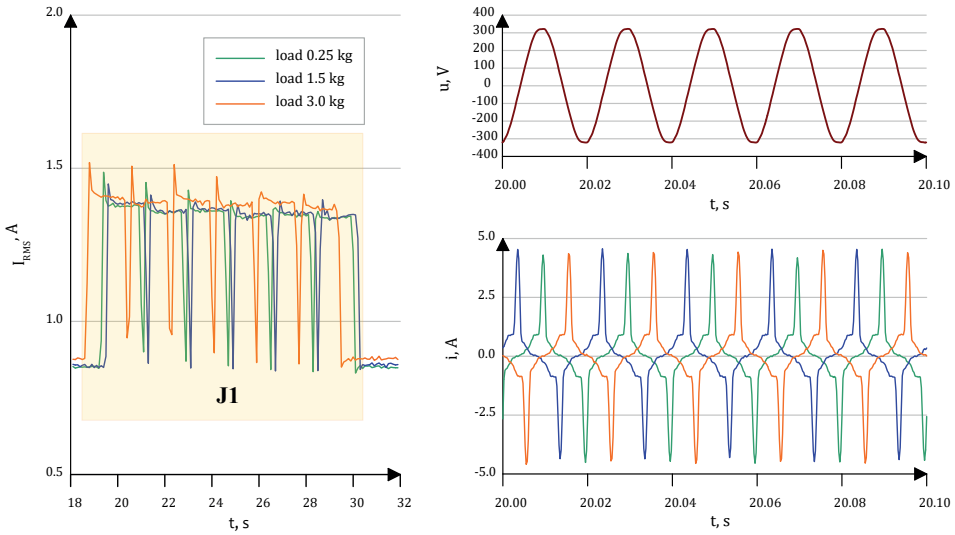


Fig. 6. Graph of changes in effective current values and waveforms of instantaneous voltage and current values in selected time intervals for J1 axis and different loads on the arm of the tested robot

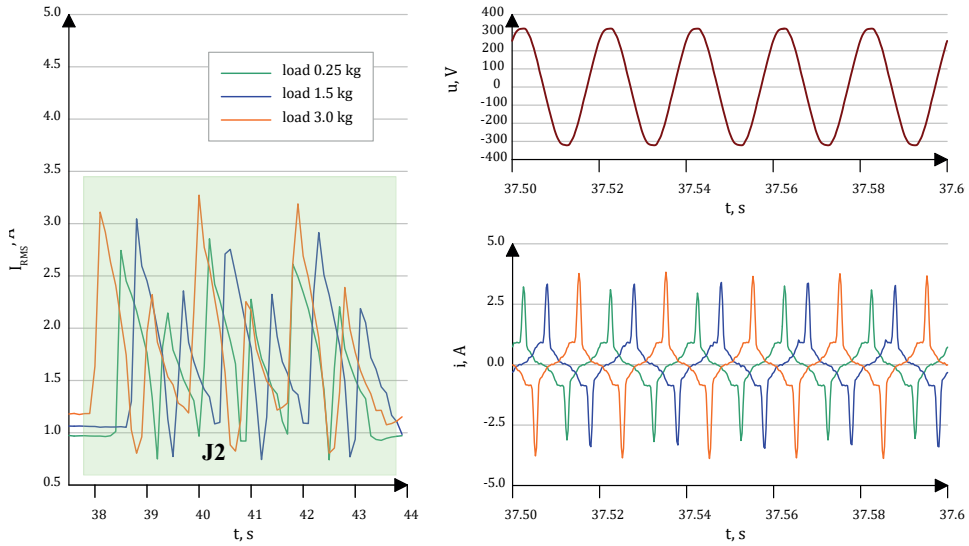


Fig. 7. Graph of changes in effective current values and waveforms of instantaneous voltage and current values in selected time intervals for J2 axis and different loads on the arm of the tested robot

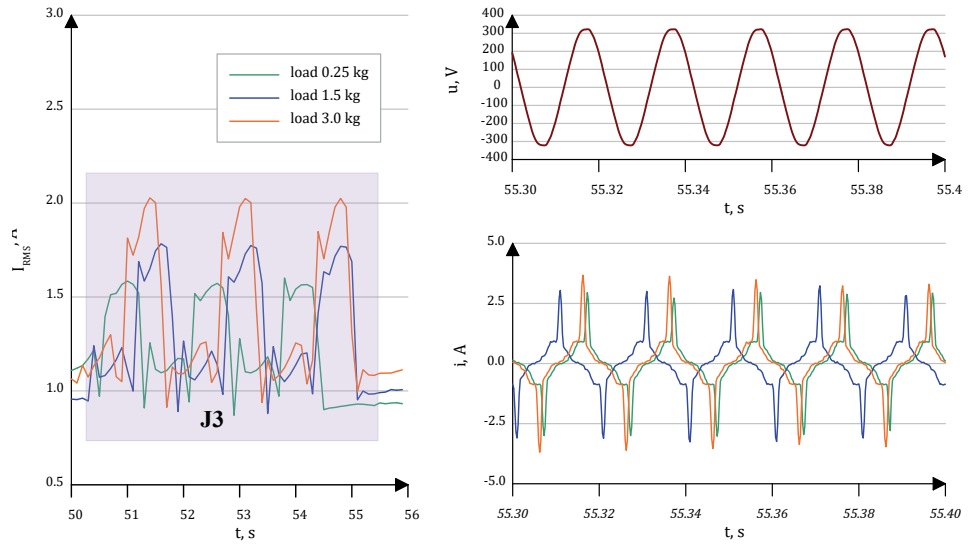


Fig. 8. Graph of changes in effective current values and waveforms of instantaneous voltage and current values in selected time intervals for J3 axis and different loads on the arm of the tested robot

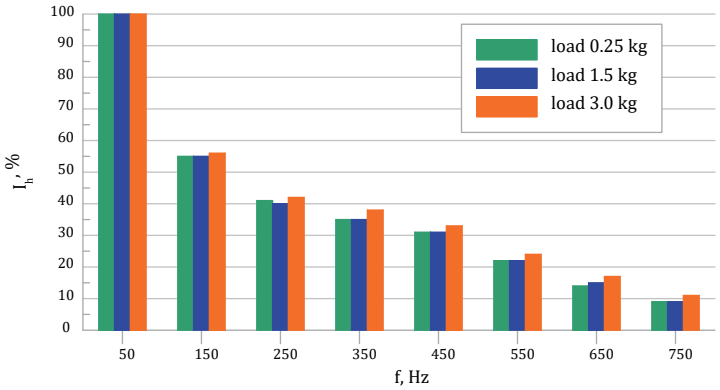


Fig. 9. Graph of percentage values of odd current harmonics for the assumed loads on the arm of the tested robot

Table 1
THD_U and THD_I values for each axis of the tested robot

Load	THD_U, %	THD_I, %
0.25 kg	2.2	86.7
1.5 kg	1.9	86.8
3.0 kg	1.7	91.1

The analysis of the graph presented in Figure 9 and Table 1 shows that the THD_U values are practically acceptable in contrast to THD_I values. The amplitudes of the 3rd, 5th, 7th and higher odd current harmonics significantly exceed the permissible values specified in the standard [8–11].

The analysis of harmonics was also carried out in the case of a 3.0 kg load on the robot arm, programmed to perform simultaneous rotations of all axis at a speed equal to 20% of the maximum values. The values THD_U = 1.7% and THD_I = 96.0% have been obtained.

Such high THD_I values require the filtering of higher odd harmonics of the current. Filtering, especially in the case of using a large number of robots powered by a specific electrical energy source, can primarily reduce thermal effects, thereby lowering active power consumption, extending the lifespan of devices, and minimizing the potential for the malfunctioning of protective systems.

4. CONCLUSIONS

The analysis of the measurement results of instantaneous voltages and currents in the power supply system, as well as numerical calculations of their effective values and harmonic amplitudes, revealed the occurrence of short-term peaks in the effective current value, which even exceed the established value by up to four times. The FFT analysis of the voltage in the robot's power supply system shows a low THD_U value (in the analyzed time intervals, it does not exceed 2.2%), which indicates a small distortion of the voltage from the sinusoidal waveform. Current distortions in the power supply system are characterized by very high amplitudes of odd (third and higher) harmonics.

The harmonic analysis was carried out at a laboratory station equipped with one robot with a single-phase controller. Further tests are planned with a larger number of robots, including three-phase ones.

Proper filtering of such current distortions in the robot's power supply system can improve the quality of electrical energy, thereby reducing the generation of power disturbances in electrical and electronic devices. A well-designed harmonic filtering system will have a direct impact on the cost of consumed electrical energy and other operational costs, also linked to the ecological and organizational aspects of foundry production processes using robots.

ACKNOWLEDGEMENTS

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