The analysis of energy consumption of the transport and manipulation process of Fanuc AM100iB robot

A Cholewa\textsuperscript{1}, J Świder\textsuperscript{2} and A Zbilski\textsuperscript{3}  
\textsuperscript{1,2} Silesian University of Technology, Faculty of Mechanical Engineering, Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Konarskiego 18A, 44-100 Gliwice, Poland  
\textsuperscript{3} DRÄXLMAIER Group, Engineering Department, Wincentego Pola 21, 44-100, Gliwice, Poland  
E-mail: adam.cholewa@polsl.pl

Abstract. This article describes test results of energy consumption of Fanuc ArcMate 100iB robot during realization of the transport and manipulation process. The energy consumption test involved the acquisition of values of angular positions of the robot's encoder shafts and values of tensions and expansions of the electrical currents in three phases of each engine. Based on the simulation results, the analysis of energy consumption was carried out, which specified the tested palletizing process using the set of complete and partial decompositions of the energy consumption of all these factors, which in significant degree impacted the amount of energy taken during the process. Quality of the data provided by the analysis of energy consumption was assessed through validation of results, which involved direct comparison of corresponding parameters, which values were measured and calculated. With regards to the developed analysis of energy consumption, computerized techniques were used to determine the impact of all material factors on the total energy consumption of the machine. The work presents the most significant results of the obtained outcomes.

1. Introduction  
The study of energy consumption of industrial robots, for which the preparation process of models has been described in [1][2][3], included the analysis of energy consumption of the process of transport and handling. The analysis consisted of determining the amount of mechanical energy expended by each of the factors, having an impact on energy consumption in propulsion systems of the tested machine.

2. Research results  
It was assumed that the analysis of energy consumption will be implemented in a way making it possible to track the impact of instantaneous values of all required parameters on the total electricity consumption. For this purpose, a system was developed for calculating the power and mechanical energy expended to overcome all types of loads and to calculate the power loss and the power drawn from the electrical network, and which also operates in real time. The system consists of six identical subsystems, assigned to six robot joints. Each subsystem collects signals with the values of driving torques obtained and the values of kinematic parameters obtained, as well as signals with the calculated values of total and partial torques, putting a load on the motor shaft. At the entrance, each
subsystem also collects power loss maps, suitable for the motor used in the analysed joint. Based on the input data, the subsystem calculates the total and partial power, as well as mechanical energy, power, energy losses and the total amount of electricity drawn by the analysed joint, and the cost of this energy. Blocks storing passive and active power loss maps were used for the calculation of power loss. The model employed normalized power loss maps, which were used for the analysed motor using normalisation and reduction of the maximum values of rotary speeds and driving torques achieved.

The study of energy consumption was conducted for the exemplary process of transport and handling, namely the process of palletizing. The study consisted in acquiring the values of angular positions of the robot encoder shafts and the values of voltages and strengths of electric currents in three phases of all the motors.

Angular positions of encoder shafts were converted to the values of angular positions of the robot's units, and instantaneous values of power of the electric current consumed were calculated on the basis of the values of voltages and strengths of electricity.

The values of kinematic parameters obtained in this manner were applied to the numerical model of the robot, in the form of a position signal of the angular encoder shafts, recorded in the time domain. Automatic position adjustment systems of the CAE robot's model calculated the values of the angular velocity and the values of the signal of the driving torques on the shafts in all motors of the machine. The angular velocities of the motor shafts and the robot's units measured indirectly, and the calculated values of the driving torque were used to calculate the energy consumption of all the required factors [5]. The analysed palletizing process consisted of transporting and changing the orientation of 4 elements with a weight of 5 kg each, at maximum capacity. The work of the robot was carried out in accordance with a robot program prepared for this purpose.

Sample input data for the CAE model [4] are shown in figure 1, figure 2 and figure 3.

![Figure 1. Angular position of robot's units during the palletizing process [3].](image)

Accurac
ya of mapping the kinematic values of the robot using its numerical model was considered satisfactory, and therefore there was no need for correction adjustments to the control systems of the CAE model.

Simulation results were gravity force moments, acting on the robot's units during the palletizing process, moments of the centrifugal forces and Coriolis forces, acting on the robot's units during the palletizing process, moments of inertia forces, acting on the robot's units during the palletizing process, and moments of friction forces, acting on the motor shafts of the robot during the palletizing process.
An analysis of energy consumption was performed based on the results of simulation, which specified the analysed palletizing process using a set of total and partial distributions of energy consumption of all these factors, which significantly affected the amount of energy taken during the process.

The set of data describing the energy consumption of the analysed process includes: power expended to overcome the force of gravity acting on the robot's units during the palletizing process, the power expended to overcome the centrifugal and Coriolis forces, acting on the robot's units during the palletizing process, the power expended to overcome the inertia forces acting on the robot's units during the palletizing process, the power expended to overcome the frictional forces acting on the

---

**Figure 2.** Angular velocities of robot's units during the palletizing process [3].

**Figure 3.** Trajectory of movements of the robot's TCP point during the palletizing process [3].
motor shafts of the robot during the palletizing process, the total power expanded to overcome dynamic resistance of movement, acting on the motor shafts of the robot during the palletizing process, active power losses in the robot's motors during the palletizing process, passive power losses in the robot's motors during the palletizing process and the distribution of power in the robot's motors during the palletizing process.

In terms of the amount of total energy collected by each of the factors affecting the energy consumption, the analysis carried out specified the analysed process using the set of data, comprising: distribution of the energy of gravitational forces acting on the robot's units during the palletizing process, distribution of the energy of centrifugal forces and Coriolis forces acting on the robot's units during the palletizing process, distribution of the energy of inertial forces acting on the robot's units during the palletizing process, distribution of the energy of frictional forces acting on the motor shafts of the robot during the palletizing process and the distribution of the total energy of the resistance of movement acting on the motor shafts of the robot during the palletizing process (figure 4).

![Figure 4. Distribution of the total energy of the resistance of movement acting on the motor shafts of the robot during the palletizing process [3].](image)

Distribution of the total energy from movement resistance indicates very clearly the dominant role of the moments of friction forces in energy consumption in the analysed palletizing process. This is due to the viscous properties of movement resistance in mechanical transmissions, whose energy consumption depends on the relative speed of the cooperating components. In the analysed example of the palletizing process, the angular velocity of the first unit had the highest values, right after the sixth unit, which in the case of the highest mechanical transmission in the machine results in a maximum value of the friction torques.

Distribution of the total energy of motion resistance acting on the motor shafts of the robot palletizing during the process (figure 4) summarises the results of the analysis of energy consumption of the analysed palletizing process and clearly indicates the sources of the highest consumption of electricity - the drives of the first and second unit. The causes and the degree of their impact on the total energy consumption of the process are identified in the remaining results of the analysis of
energy consumption, and their direct mutual comparison is described by indicators of energy consumption in the palletizing process (figure 5).

![Figure 5. Indicators of energy consumption during the palletizing process [3].](image)

Energy consumption indicators show the highest energy intensity of friction torque in the first joint during the whole palletizing process, which in this case was also identifiable on the basis of the results of energy consumption. The next parameter with similar value of energy consumption, according to the indicators, was the moment of gravity force of the third unit, working in the second joint, and the moment of gravity force of the second unit, working in the second joint. We can describe all the factors that affect the energy consumption in a similar manner, however, it is the most justified to consider only those which in the analysed process had the strongest impact on the amount of energy consumed.

![Figure 6. Comparison of the calculated and measured distribution of power in the robot's motors during the palletizing process. Total instantaneous power in the robot's joint [3].](image)

The quality of energy consumption data provided by the analysis was assessed using the validation of results, involving the direct comparison of corresponding parameters whose values were measured.
and calculated. To this end, a comparison was conducted of the total instantaneous power drawn by each of the robot drives (figure 6) and a comparison of the amount of energy drawn by these drives (figure 7).

![Figure 7](image)

**Figure 7.** Comparison of the amount of energy drawn by each of the robot drives [3].

### 3. Summary

Validation of energy consumption during the palletizing process showed a satisfactory coincidence between the total measured instantaneous power and the calculated total instantaneous power, and between the measured total input energy and the calculated total input energy supplied to the robot's motors. On the other hand, there are large differences between the values of partial energy drawn by the robot's drives. Explanation of this discrepancy needs further testing of the machine's drives and refining its numerical model.

Due to the limited size of the paper, a graphical representation of some of the research results are presented. Complete test results are summarised in the paper [3].

### 4. References

[1] Cholewa A, Świder J and Zbilski A 2016 Numerical model of Fanuc AM100iB robot *IOP Conf. Ser.: Mater. Sci. Eng.* 145 052002

[2] Cholewa A, Świder J and Zbilski A 2016 Verification of forward kinematics of the numerical and analytical model of Fanuc AM100iB robot *IOP Conf. Ser.: Mater. Sci. Eng.* 145 052001

[3] Świder J, Cholewa A and Zbilski A 2015 *Komputerowo wspomagana analiza energochłonności napędów elektrycznych maszyn w procesach transportu i manipulacji* (in Polish); (Gliwice)

[4] Gwiazda A, Foit K, Banaś W, Sękala A and Monica Z 2015 Analysis and optimization of the piston system using CAD/CAE engineering environment *Applied Mechanics and Materials* 809-810 1662

[5] Monica Z, Sękala A and Gwiazda A 2016 Application of the advanced engineering environment for optimization energy consumption in designed vehicles *IOP Conf. Series: Materials Science and Engineering* 145 661-666