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Modeling, analysis and effective improvement of aluminum bowl embossing process through robot simulation tools

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Abstract

This paper discusses the development of an automated loading and unloading system for aluminum bowl embossing operation on a power press machine. Presently the operation under consideration is manual. The worker manually picks the bowl from the input bin and places it onto a press bed for stamp embossing and after completion, removes the embossed bowl and places it into an output bin. Compared to conventional embossing techniques, bowl embossing includes fewer manufacturing steps and is therefore likely to be better suited for automated production. Automation of the bowl embossing production step is a crucial task in order to lower the manufacturing costs of these aluminum bowls. For studying manual loading/unloading conditions of the worker, a detailed Time and Motion analysis of worker is carried out. On the basis of cycle time analysis results, an alternative to the manual operation, a more sophisticated automated loading/ unloading system is suggested. The viability of the suggested system is checked through simulation and cycle time analysis. A proposed system which uses a robotic manipulator and a feeding system is also developed and tested. The software used for analysis, CAD model development and simulation is Delmia V6. A real case study belonging to aluminum bowls manufacturing scenario is simulated and its embossing process is used as a reference in this paper. From this example, it is shown that considerable production cycle time and manufacturing cost savings can be anticipated compared to manual loading/unloading. The suggested automation method is very flexible. It can be used for the production of aluminum bowls embossed with different shapes, sizes, and with different embossing patterns.

Keywords: Modeling; Robot simulation; DELMIA V6; Robotic manipulator; Bowl embossing

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1. Introduction

There has been increased demand both domestically and internationally for embossed aluminum bowls used as containers for food or water. It has been recognized that automated aluminum bowl embossing processes are necessary to this production industry. Designing with production in mind has been an important key in the process towards automation of aluminum bowl embossing. The pick-transfer-and-place operation of the bowl on the power press machine is presently being done manually by the worker. One of the most challenging operations to automate in aluminum bowl manufacturing industry is the machine loading and unloading. The real process has some important advantages, including reduced system losses and fewer embossing steps.

The US Bureau of Labour Statistics reported that repetitive placing, grasping, and moving objects accounted for 31% of non-fatal occupational injuries in private industry workplaces that were associated with repetitive movement [1]. Production losses may occur due to the fact that each worker initially needs more time to reach and stabilise their proficiency levels in operations as required through training in a learning and forgetting process [2], [3]. The aim of the work described in this paper was to model and analyze the aluminum bowl embossing process, with a particular focus on robotic manipulator applications to replace human labor for aluminum bowl handling tasks, specifically for picking, transferring and placing, which have been identified as the most frequently encountered tasks in this exciting manufacturing cell and currently performed manually. Their analysis and providing the automation would greatly improve the productivity and cost effectiveness of this industry. However, no publication describing fully developed automated aluminum bowl embossing production method has been found.

Employment of robots in manufacturing has been a value-added entity for companies in gaining with competitive advantage. With the advent of more affordable and more easily programmable robot manipulators [4], many manual tasks in production lines are being reconfigured by automation integrators to accommodate robots and other automated equipment alongside humans in order to increase productivity. Zomaya [5] describes some features of robots in industry, which are decreased cost of labour, increased flexibility and versatility, higher precision and productivity, better human working conditions and replacement of humans working in hazardous and impractical environments.

The advent of computer technologies allows management to analyze and predict many sophisticated manufacturing problems. Computer simulation helps one plan, create, implement, and modify a manufacturing system [6]. Therefore, simulation can be used as a management tool in order efficiently and productively to minimize costs and maximize output. This is especially true when high cost and risk are involved in the process of decision making [7]. Robotic simulation covers the visualization of how the robot moves through its environment. Basically, the simulation is heavily based on CAD and graphical visualization tools. Other type of simulation is numerical simulation, deals with dynamics, sensing and control of robots. It has been accepted that the major benefit of simulation is reduction in cost and time when designing and proving system [8].

Robotic simulation is a powerful tool which is extensively useful in industry in order to save money and end users time while designing a robotic workcell. User can predict the behavior of workcell prior setting up actual process and thus can save both time and money. Robotic simulation allows smoother transition from concept to reality giving user a freedom to make mistakes, study and analyze them while designing the workcell. Many industries are now recognizing simulation as a viable tool as it provides better manufacturing designs and also offers cost benefits in engineering and installation benefits [9]. Robotic simulation is a kinematics simulation tool the primary uses of which are as a highly detail, cell-level validation tool [10] and for simulating a system whose state changes continuously based on the motion(s) of one or more kinematic devices [11].

This paper presents how to generate a computer based model of a machine loading system in order to monitor and evaluate a robotic manipulator application system through simulation. The simulation will focus on movement of a robotic manipulator to pick a blank aluminum bowl from the feeder, load it onto the power press machine, rotate step by step in each embossing stamp, and then unload the embossed aluminum bowl into the bin.

The remainder of this paper is organized as follows: Sections 2 presents the blank aluminum bowl feeding system to the current production machine. Section 3 discusses how to develop automated manufacturing workcell. Some simulation and results are analyzed in section 4. The working of prototype is in section 5, and conclusions are drawn in section 6.

2. Current Manufacturing Workcell

2.1. Aluminum bowl embossing process

In our case study, the production industry of embossed aluminum bowl is a manufacturing scenario. The process has many steps, starting from aluminum sheet to forming through the process until the embossed aluminum bowl as shown in Fig. 1. However, as mentioned in Section 1, some current workcells still employ workers to pick blank bowls from the input bin, one at a time to the press bed of the power press machine, rotate the blank bowl relative to stamping controlled by the foot switch and then remove the embossed aluminum bowl and drop it into the output bin. The present workcell is shown in Fig. 2.

Fig. 1. Embossed aluminum bowl

Fig. 2. Present manufacturing workcell

2.2. Modeling of current manufacturing cell

The machine loading by human worker as shown in Fig. 2 can be modeled as a workcell using Delmia V6 software. Modelling such a workcell by selecting the geometry and parametric data of the human from the library, as well as specifying the components of the workstation and then executing the simulation to determine the cycle time, work with people, is referred to as human cycle time (CT) as shown in Fig. 3. The workcell process is shown in the Pert process chart, as shown in Fig.4.

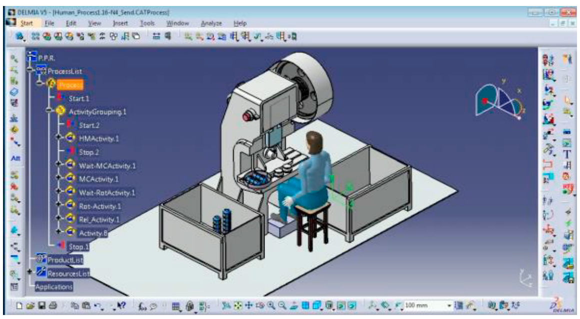


Fig. 3. Modeling workcell layout

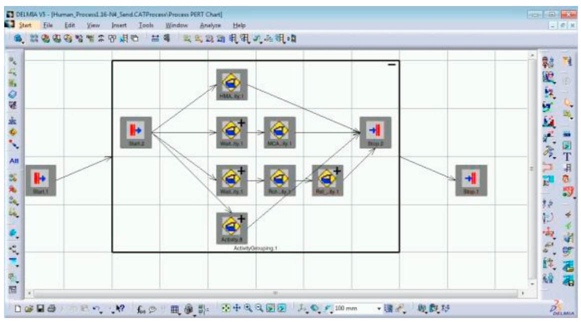
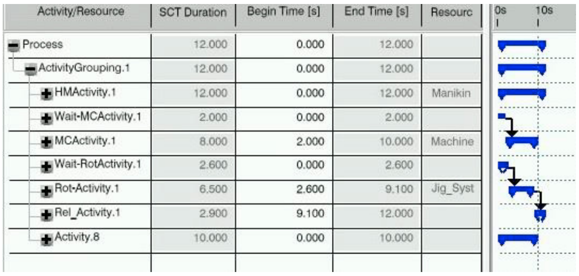


Fig. 4. System Pert process chart

2.3. Human workcell simulation

The simulation of a human workcell using one of the work measurement technics called Method Time Measurement (MTM) of a person who has been given a real-time workout. When simulating, the motion of activities corresponds to the time in the process as shown in Gantt chart in Fig. 5.



Activity/Resource	SCT Duration	Begin Time [s]	End Time [s]	Resourc
Process	12.000	0.000	12.000	
ActivityGrouping.1	12.000	0.000	12.000	
HMActivity.1	12.000	0.000	12.000	Manikin
Wait-MCActivity.1	2.000	0.000	2.000	
MCActivity.1	8.000	2.000	10.000	Machine
Wait-RotActivity.1	2.600	0.000	2.600	
Rot-Activity.1	6.500	2.600	9.100	Jig_Syst
Rel_Activity.1	2.900	9.100	12.000	
Activity.8	10.000	0.000	10.000	

Fig. 5. Process Gantt chart

The process of embossing the aluminum bowl as mentioned in Section 2.1, cycle time can be analyzed from the Process Gantt chart;

HMActivity is referred to as cycle time = Wait_RotActivity + Rot_Activity + Rel_Activity
= 2.6 + 6.5 + 2.9
= 12 sec

Where,
Wait_RotActivity = loading + 1 stamping,
Rot_Activity = 7 Rotating + 6 stamping, and
Rel_Activity = 1 stamping + unloading + retuning (move to loading station)
Thus,
Loading time = 2.0 sec
Stamping time = 0.6 sec
Rotating time = 0.4 sec (simultaneously machine backward)
Unloading time + Returning time = 2.3 sec

As a simulation, it is seen that the cycle time = 12 seconds. If speeding up the demands of the job is needed, it is only possible to reduce the CT, such as reducing loading, unloading, and returning time. The rotating time and the time in actuating the machine controlled by the foot switch cannot be reduced, since it must be related to the operation of the machine. However, there are certain effects and physical demands of speeding up the demands of the job by reducing the CT [12]. It results in, muscle pain and tenderness of the neck and shoulder areas, and forearm extensors for workers. Neck and shoulder complaints are also common in repetitive tasks, if the CT is reduced.

3. Development of Robotic Workcell

In terms of the simulation and analysis results of the present system, it is seen that speeding up the demands of the job can only be done by replacing the human workers with automated devices; a robotic manipulator and feeding device.

3.1. Robotic workcell modeling

The methodology for developing a robotic workcell is based on the present workcell simulation results in Section 2.3. Using Delmia V6 software, the following steps are:

Modeling of 3D geometry:

The manipulator components, feeding device, including workstation components such as the power press machine and workpiece are modeled as the robotic workcell is shown in Fig.6.

Defining of work cell component parameters:

This provides the ability to select and position the various components of the active devices and tools including manipulators and sensors. The manipulator components, power press machine, and feeder having following specification.

Cylinder (x): Stroke = 1000 mm, Max. Speed = 1500 mm/sec
Cylinder (y): Stroke = 520 mm, Max. Speed = 560 mm/sec
Rotary (b): Oscillation Angle = 360 deg, Speed = 600 deg/sec
Power press machine: Cycle Stroke = 1 sec
Feeder: Travers speed is related to the cycle time

The robot workcell process is shown as a Pert process chart in Fig.7.

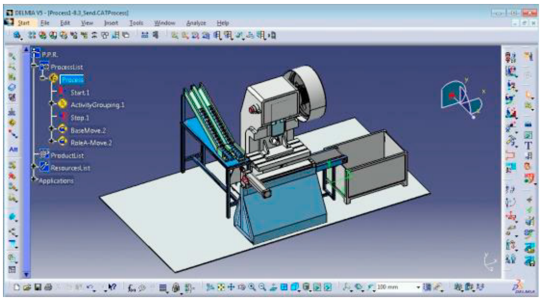


Fig. 6. Robotic workcell

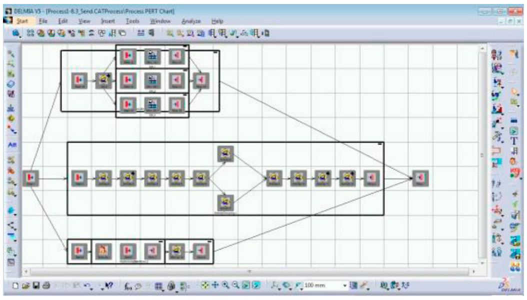


Fig. 7. System Pert process chart

3.2. Simulation

This uses geometric modeling and kinematic analysis to simulate the movement of a robotic manipulator and other active devices. Beside that the robotic workcell are being simulated as shown in Fig. 8. The best performance of simulation of the robotic workcell can be demonstrated by the process Gantt chart in Fig. 9.

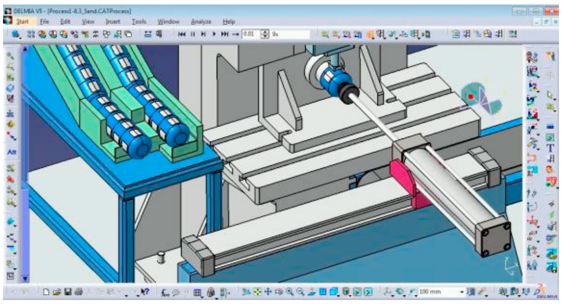


Fig. 8. Robotic wotkcell simulation

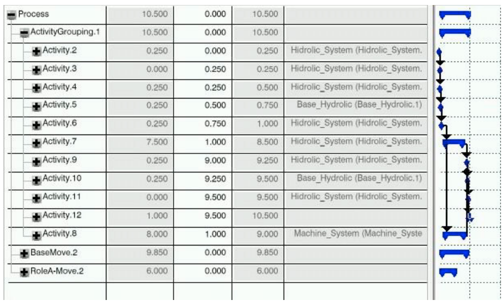


Fig. 9. Robotic wotkcell process Gantt chart simulation

3.3. Economic calculations

A new automated robotic cell should be economically evaluated and compared to present production methods. One important figure, used to determine the value of the investment, is the net present value, which is calculated using Eq.(1) where *EUAC* is the equivalent uniform annual cash, C_t is the net cash flow at time t, n is the economic life time of the investment, A/P is the capital recovery factor. Another useful figure is the payback period, which is calculated by solving Eq.(2) where T is the payback period.

$$EUAC = -Investment\ cost\ (A/P,30\%,n) + Annual\ income - Operation\ cost \quad (1)$$

$$\sum_{t=0}^{T} C_t = 0 \quad (2)$$

4. Analysis of Robotic Workcell

4.1. Robot cycle time analysis

A similar approach to MTM has been developed for analyzing the cycle time of robot operation. A method known as RTM (for Robot Time and Motion) is useful for estimating the amount of time required to achieve certain work cycle time prior to the provision of workstation and robot programming [13]. The robot work cycle element can be broadly categorized into; 1) Motion elements, 2) Sensing elements, 3) End effector elements, and 4) Delay elements.

According to the process Gantt chart in Fig. 9, the robot cycle time can be obtained from time that manipulator robotic is involved in all activities. In addition, all activities time shown in this process Gantt chart can be grouped into four groups which are; Load, Rotate and Stamp, Unload, and Back to Start activities. Four activities times can also be classified into the robot cycle time element as follows:

1. Load activity is Motion + End effector + Sensing elements
2. Rotate and Stamp activity is Motion + Sensing elements
3. Unload activity is Motion + End effector + Sensing elements
4. Back to Start activity is Delay elements

Therefore, robot cycle time for this robot workcell will be;
Load + Rotate and Stamp + Unload + Back to Start times = 1.00 + 8.00 + 0.60 + 0.90 = 10.5 seconds

4.2. Economic analysis

To make an economic analysis of automated embossing, the total investment cost of one robotized manipulator bowl embossing manufacturing cell, as presented in this paper, must be roughly estimated. The dominating cost unit is the robotic manipulator and feeding system, the total investment cost can be calculated to be about 325,000 Baht (33 Baht = US dollar).

The production of one automated robotic manipulator cell, one lot order per 1333 min, should be compared to the production through manual embossing one lot order per 3333 min with one personnel. This gives a rough approximation that the production of one robotized manipulator embossing cell is equal to the production of about 2.5 manual embossing cell. By comparing the investment and operation costs for one automated robotized embossing cell to the operation costs for 2.5 manual embossing cell, an economical evaluation of the robot cell can be performed. The cost parameters for automated embossing are; 1) operation costs including maintenance, electricity, and robotic manipulator installation and commissioning costs = 65,000 Baht, 2) annual income per year = 500,000 Baht.

Using Eq. (1), *A/P* with *MARR* = 30%, and *n* = 5 years, the equivalent uniform annual cash of the embossing automation investment, compared to manual embossing, can be calculated to about 301,562 Baht. The payback period, compared to manual embossing, can be calculated from Eq. (2) to about nine months.

5. Working of Prototype

The prototype of loading/unloading system is chosen and constructed together with the results from section 4.

Fig. 10. The loading/unloading system

The loading/unloading system as shown in Fig. 10 consists of a robotic manipulator and a bowl feeder. For a robotic manipulator, there are 3 degree of freedom (DOF) joints, which are two linear joints, the *X*- and *Y*- axes, and one rotating joint that rotates around the *Y*-axis is the *b*-axis. All 3 axes is a modular design with built in controller, which is purchased from the manufacturer and then assembled together. The *Y*-axis is perpendicular to the *X*-axis and the *b*-axis is attached to the *Y*- axis end, the specification of all axes as described in section 3. The *b*-axis equipped with End effector which is a suction cup gripper, is used to pick a bowl which is fed out of the feeder. The feeder is a magazine pressurized air, it can pack 30 blank bowls, which is fed out one by one. The robotic manipulator and a bowl feeder are installed and interfaced with the power press machine by means of sensors as input and output interlocks, that plays an important role in sequence control of the work cycle.

The operation will be carried out as follows:

1) The robotic manipulator moves forward to a feeder and pick a blank bowl from the feeder.
2) The robotic manipulator transfers a blank bowl to the power press machine, and places onto the press bed of machine.
3) The power press machine then embossing stamps and gripper rotates 45 deg., each rotates corresponds to a stamping stroke, 7 rotates and 8 stamps.
4) When the embossing is completed, the robotic manipulator unloads the embossed bowl into the output bin. Go to step1.

5.1. Experimental results

The performance of automated bowl embossing workcell compared to originally bowl embossing workcell is shown in Table 1.

Table 1. The performance of bowl embossing workcells.

Performance	Manually loading/unloading	Automated loading/unloading
Cycle time (sec)	20	8
Bowl per Minute	3	7.5
Bowl per day	1140	3600
Bath size = 40000 bowls	28 days	17 days

6. Conclusions

The cycle time analysis is carried out on the present machine loading/unloading and results have shown the need for change in the loading/unloading system which is automation. Thus the development of an automated loading/unloading system is justified. The development of working prototype of the automated loading/unloading is done. The suggested robotic manipulator is an economic option available instead of dedicated Robotic Systems available in the market. After implementing the proposed system the cycle time of the operation will be reduced and labour cost will also be reduced. The proposed system can work continuously without much downtime so that significant productivity gain can be obtained. This system requires low maintenance and is easy to install. Further development in the system can be done such as using two robotic manipulators as well as two feeders supporting one power press machine so that the productivity will be improved. By using various sensors such as proximity sensors, force/pressure sensors proper gripper positioning can be done. A gripper adjustment option can be incorporated so that variable diameter bowls can be handled.

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