Design of pick and place and color sorting system using VDI 2221

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Abstract. In order to satisfy people’s needs in Industrial era 4.0, many varieties of industrial system design have been developed especially in mechanical and automation sector. One of the examples is the pick and place system. This design aims to show the use and workings from combination of pick and place system and color sorting system. Pick and place system used is a single axis robot with two degrees of freedom and aluminium profile frame. Arduino and TCS230 sensor is used in the system. Design method uses VDI 2221 frame. The chosen design result is variant (5) with a total weighting of VDI value is 7.3175. The calculation in the design is maximum deflection calculation that occurs in the aluminium profile frame which is equal to 3.1263 x 10^-18 m. The pick and place system on the x axis uses a single axis robot type KK60 lead 10 mm which is able to lift 1 kg loads and move at a maximum speed of 790 mm/s as far as 220 mm, while on the z axis uses a single axis robot type KK40 lead 1 mm which is able to lift 0.066 kg loads and move at a maximum speed of 190 mm/s as far as 30 mm. The servo motor used has a torque value of 0.48 Nm for 50 W and 0.96 Nm for 100 W. Keywords: design, single axis robot, color sorting system.

1. Introduction
Entering the Industrial Era 4.0 as now, various industrial system designs can be found such as in the mechanical and automation fields. One opinion regarding the potential benefits of Industry 4.0 is about improving the speed and flexibility of production [1]. The design of the industrial system is expected to be able to run effectively and efficiently, and be able to answer the challenges of today’s industrial needs. Various kinds of production support systems are often found in the industrial world, one of them is a pick and place system that can be combined with other automation systems. In designing the pick and place and color sorting system, it is explained that the existence of a control system is very important in supporting a production process, especially in the industrial world [2-3].

In the system design, a design is made based on the design method of VDI 2221 which can formed a coherent framework. This design aims to show the use and workings from combination of pick and place systems using a single axis robot and a color sorting system using the TCS230 color sensor, which can be applied in the industrial world, especially in the field of automation. This design is expected to be able to obtain the design, kinematics and dynamics calculation data that occur, and produce prototype of machine that work automatically. This is certainly also closely related to the selection of materials to be used in the design and manufacture of prototype [4-9].
2. Method
Method used in the design is VDI 2221 design method. Concept design is done by following the procedure below:
   a) Make the clarification of the task
   b) Identify conceptual design and embodiment design
   c) Create the detail design
   d) Pick the material used in the chosen design
   e) Adjust design specifications of the prototype
   f) Create a prototype and 3D model.

3. Result and Discussion
The design method of pick and place and color sorting system used is the VDI 2221 frame. As an initial reference in this design, a wishlist or initial specification is set according to the requirement between demand or wishes. This step is done in order to clarifying the tasks which want to achieved in a design. After determine the initial specifications, the principle of subfunction solutions need to be made to select the components that need to be used in the design of pick and place and color sorting system. The principle solution can be made as much as possible with the aim of obtaining product with high efficiency value. After making the principle of subfunction solutions, the next step is to make possible combinations that can formed the most appropriate system in making several variants. The combinations of the principle of subfunction solutions can be seen in Table 1.

Table 1. The combinations of the principle of subfunction solutions

| No. | Principle of Solutions Sub-function | A                  | B                  | C                  |
|-----|-------------------------------------|--------------------|--------------------|--------------------|
| 1.  | Driver                              | DC Servo Motor     | AC Servo Motor     | Air                |
| 2.  | Power Successor                     | Single Axis Robot  | Ball Screw         | Rodless Cylinder   |
| 3.  | Construction                        | One Support System | Two Support System | -                  |
| 4.  | Material System of Framework        | Aluminium Profile  | Iron               | Steel              |
| 5.  | End Effector                        | Gripping Force     | Fom Gripper        | Vacuum             |

V6  V3  V2  V1  V4  V5
Based on the principles of the solution described, it can be concluded that the combination or variants formed are as follows:

a) Variant 1: C1 → C2 → A3 → B4 → C5  
b) Variant 2: B1 → A2 → B3 → A4 → B5  
c) Variant 3: A1 → B2 → B3 → C4 → A5  
d) Variant 4: A1 → A2 → A3 → A4 → C5  
e) Variant 5: B1 → A2 → A3 → A4 → C5  
f) Variant 6: B1 → A2 → A3 → A4 → A5

After a combination or variants have been made, to determine the variants that may be continued in this design process, a selection of the existing variants must be made. One way for variant selection can be done by using a selection chart.

Table 2. Selection of solution variants

| Selection Chart | Solution variants (SV) evaluated by: | Decision. Mark solution variants (SV): |
|----------------|--------------------------------|---------------------------------|
| (+) Yes        | (-) No                         | (+) Yes                         |
| (? ) Lack of information | ( ! ) Check requirements list | (-) Eliminate solution |
| ( ! ) Check requirements list |                      | (+) Pursue solution |

Compatibility assured

- Fulfils demands of requirements list
- Realisable in principle
- Within permissible costs
- Incorporates direct safety measures
- Preferred by designer’s company
- Fulfils safety requirement

| Remarks         | SV |
|-----------------|----|
| Not Appropriate | -  |
| Appropriate     | +  |
| Not Appropriate | -  |
| Appropriate     | +  |
| Not Appropriate | -  |
| Appropriate     | +  |
| Not Appropriate | -  |

From Table 2 above, it can be seen that the variants which meet the design criteria are variant 2 and variant 5. By calculating the most possible to be created in prototype form, then variant 5 was chosen with a total weighting of VDI value is 7.3175. This variant will be continued to the next process, which called detail design.

Pictures and dimensions of the design of pick and place and color sorting system based on variant 5 can be seen in Figure 1 and Figure 2.
In order to support the load of Single Axis Motor, an 80x40 mm aluminium profile is used to be bolted to the table with six angle brackets. The angle bracket supports used in the design are a variant of sliding sleeve support type [10]. The calculation of the forces that occur in a system caused by an aluminum profile support and angle brackets can be described in Figure 3.
Based on the analysis of calculations on both axes, can be obtained that the vertical force of supports that occurs is 0. While for the magnitude of moment that must be supported by the angle bracket support system is (−) 5.83 Nm. The aluminium profile used has a polar moment of inertia that equal to 798,300 mm⁴. After finding the moment and moment of inertia of the aluminium profile support, the calculation is continued by looking for the maximum deflection that occurs in the aluminum profile. The maximum deflection value based on the calculation is 3.1263 x 10⁻¹⁸ m.

The pick and place system used in the design is single axis robot. Single axis robot has a combination of system components such as ballscrew and block that can convert rotary motion of the AC servo motor to linear translational motion. Based on the calculation formula in Hiwin catalogue [11], the ballscrew rotational speed that occurs in the single axis robot for the KK40 type is 11.400 r/min and for the KK60 type is 4.740 r/min.

Each single axis robot has different movement speed. For type KK40, it has optimal speed at 711 mm/s and maximum speed at 790 mm/s. For type KK60, it has optimal speed at 171 mm/s and maximum speed at 190 mm/s. The optimal speed value obtained from 90% of each maximum speed for some reasons, such as to provide safety factor, to increase the lifetime and also to reduce the failure risk of the servo motor, linear guideway, and ballscrew. The torque value needed to move the ballscrew in the single axis robot can be calculated with this following formula: [12-14]

\[ Tu = 0.177 \times F_{\text{Load}} \times L \]  

(1)

The results of calculation for the single axis robot is shown in Table 3.

| No. | Calculation                  | Type KK40          | Type KK60          |
|-----|------------------------------|--------------------|--------------------|
| 1   | Optimal speed value          | 711 mm/s           | 171 mm/s           |
| 2   | Average time                 | 2.68 s for each object | 2.68 s for each object |
| 3   | Load momentum                | 2.417 x 10⁻⁵ kg.cm² | 0.063 kg.cm²      |
| 4   | Acceleration torque          | 6.36 x 10⁻³ Nm     | 3 x 10⁻² Nm       |
| 5   | Moment of inertia            | 55.890 mm⁴         | 48.580 mm⁴        |
| 6   | Rotational displacement      | 188.4 rad          | 138.16 rad        |
| 7   | Torque value to moving ballscrew | 1.1682 x 10⁻⁴ Nm   | 0.01763 Nm        |
| 8   | The amount of ball capacity  | 1.343 balls per h  | 1.343 balls per h |

In the mechanism of a vacuum pad, the result of force calculation due to the lifted load is 2.13 N. In the design of the pick and place and color sorting system uses 3 kinds of supporting software to make it can run well. These three programs are lightenng, Arduino software, and CX-Programmer.
The final prototype which has been made is shown in Figure 4 and Table 4.

![Prototype Image]

**Figure 4.** Prototype of pick and place and color sorting system

**Table 4.** Mechanical and electrical system

| No. | Mechanical System                                      | No. | Electrical System                      |
|-----|--------------------------------------------------------|-----|----------------------------------------|
| 1.  | Single Axis Robot (X and Z Axis)                      | 1.  | Arduino Uno                            |
| 2.  | Aluminium Profile                                      | 2.  | Programmable Logic Controller          |
| 3.  | Vacuum Pad System                                      | 3.  | Miniature Circuit Breaker              |
| 4.  | Ball Track Container                                   | 4.  | Servo Drive                            |
| 5.  | Ball Transfer Containers                               | 5.  | AC Servo Motor                         |
|     |                                                        | 6.  | Color Sensor TCS230                    |
|     |                                                        | 7.  | Vacuum System                          |
|     |                                                        | 8.  | Power Supply 24V                       |
|     |                                                        | 9.  | Power Supply 9V and Relay System PLC to Arduino |
|     |                                                        | 10. | Relay Arduino to PLC                   |

**4. Conclusion**

The design of pick and place and color sorting system has combined the integration of pick and place system and color sorting sorting system which can be applied for industrial automation sector. For the maximum deflection calculation that occurs in the aluminium profile frame is equal to $3.1263 \times 10^{-18}$ m. The system on the x axis type KK60 is able to lift 1 kg loads and moves at a maximum speed of 790 mm/s as far as 220 mm, while on the z axis type KK40 is able to lift 0.066 kg loads and moves at a maximum speed of 190 mm/s as far as 30 mm. The 3D model and the prototype have been finished. After testing the prototype, it has average time to transfer for the optimal speed at 2.68 s, and for the maximum speed at 2.45 s. The servo motor used has a torque value of 0.48 Nm for 50 W and 0.96 Nm for 100 W.
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