The Concept of Structure a Flexible Design and Manufacturing Method Focused on the Individual Production of Grippers

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Abstract. The issues presented herein cover the design and manufacture of gripping devices. The main considerations include individual geometric and material solutions as well as specialized constructions intended for specific, custom and clearly defined orders. The work presents the concept of the design and manufacture of grippers, consisting of several basic, interconnected stages. The purpose thereof is the implementation of a flexible production system at a small enterprise Ankotech. An algorithm for design and manufacturing employing manipulators and Binar products has been proposed and presented. The proposed flexible design and manufacturing algorithm of grippers employing Binar manipulators and products constitutes an innovative solution.

1 Introduction

FMS is an innovative method of manufacturing machine components using an assembly of computer controlled working subsystems which comprise a chain of machine tools and other devices. All the equipment is integrated with a shared automated system for transportation and storage of machined components and finished products together with the required tooling and other auxiliary resources for the process (e.g. manipulators, robots, measuring instrumentation as well as movable and fixed storage) – capable of carrying out automated manufacturing of a relatively broad selection of products with minimum human supervision. Integration allows for continuous and automated delivery and is based on a computer control system [1, 2].

In the FMS system, the basic operations are controlled by a computer system: a centralized or distributed solution which supervises and manages the manufacturing in a fully automated cycle. System flexibility entails easy adaptation to varying tasks and manufacturing parameters.

For example, during mechanical processing of the popular types of engine blocks, the only change is in the controlling programs carrying out operations and technological processes specific to a given engine and, when necessary, retooling the machines (switchover of the
processing tools). The FMS system allows flexibility to adapt to the changing production volume as well as facilitates correct supervision and scheduling of the works.

The development (building) of the system entails identifying the necessary manufacturing data facilitate flexible operation with the system.

The characteristics of the system are as follows:

– high flexibility of manufacturing and easy retooling,
– all processes related to the manufacturing environment as well as the manufacturing processes are integrated within a single CIM (Computer Integrated Manufacturing) data stream,
– monolithic and complete construction of modules and manufacturing cells,
– full integration of the manufacturing system with modern 3D design methods [3-7].

The present work details the concept of implementing the FMS system at the small enterprise Ankotech which deals with the design and implementation of gripping devices (grippers) utilized as the end effector for manipulators by company Binar Quick-Lift Systems AB.

2 General safety and OHS regulations for internal transport in Poland

The Regulation by the Minister of Labor and Social Policy of April 7, 2017 on the general safety and OHS regulations details the employer’s obligation in regards to providing the necessary means while carrying out transportation and storage activities by their employees. Chapter 4, titled: Internal transport and storage, §62 pt. 1 discusses the employer’s obligation to ensure proper technical equipment is made available to the employees in order to eliminate the requirement for manual handling of heavy weights; what follows further in pt. 2 of the same paragraph, if it is impossible to avoid manual handling of heavy weights, it is necessary to take the necessary technical devices to reduce the inconvenience and hazards associated with the performance of such activities. Therefore, the primary goal is to eliminate the need for the employee to manually handle heavy weights. If this proves impossible, appropriate technical devices need to be taken so that the handling process is not inconvenient and in particular does not put the employee’s life in danger [8, 9]. Therefore, if the employer provides access to the appropriate means of transportation to the employees, such means need to fulfill the relevant requirements for safe use. It is therefore relevant to quote the pts. 2 and 3 of paragraph 64 in their entirety, which define the actual issue: for point 1: “The weight and distribution of loads on the means of transportation should ensure safe conditions for transportation and unloading”. Point 2 stipulates: “The load should be secured in particular to prevent falling, movement and spilling from the means of transportation” [8, 9].

The employment and joining of properly selected and designed gripping devices [10] with manipulators by manufacturer – Binar Quick Lift Systems AB allows to achieve new, original manufacturing methods as well as the following effects:

– efficiency,
– ergonomics,
– precision,
– safety,
– simplicity,
– adaptability.

As a rule, the type and construction of the grippers [10] is to be customized to individual order. Regardless of the construction shape and functionality of the gripping device, it is
necessary for the gripper to become an integral and natural component of the transport system.

The need to fulfill the need to quickly develop manufacturing methods in all the branches of economy and social life calls for the continuous and dynamic invention of new methods of design and construction of original, highly specialized and innovative gripping devices, closely integrated with Binar manipulator systems (see Fig. 1). The concept of development a flexible design and manufacturing system focusing on the manufacturing of singular gripping devices is fully justified from both the economic and technical standpoint.

"Ankotech" strives to provide solutions for modern systemic issues used in internal transport in partnership with the Swedish manufacturer Binar Quick-Lift Systems AB, for which it acts as an exclusive trade and engineering representative in Poland. Novel and patented technical solutions for manipulations together with smart software developed by Binar Quick-Lift Systems AB may be used and applied at every stage of manufacturing, storage and unloading processes in industries such as: automotive, home appliances, metal industries, aviation, construction, military or food processing as well as in all other applications where precision and high speed together with ergonomics, ease of use and safety is a requirement. Binar Quick-Lift Systems AB develops both standard and non-standard solutions for lifting and moving items of weight up to 300kg (see Fig. 2 and Fig. 3).

Fig. 1. General concept of the approach leading to the development of a flexible manufacturing system for gripping devices.

Fig. 2. General view of a manipulator by Binar Quick-Lift [11, 12].
3 The flexible design and manufacturing algorithm for grippers

Fig. 4 demonstrates an algorithm for flexible design and manufacturing of customized gripper constructions implemented in Ankotech.

The first stage involves a detailed specification of construction and functional features of the object of manipulation/transport. These features include: geometric characteristics, material characteristics and dynamic characteristics. In relation to the gripper design process, the dynamic characteristics are to be understood as the extreme values of force generated by the operated manipulator with gripper. These characteristics are invariably related to the geometric and material characteristics. The surface condition and e.g. strength of the material used in the manipulated object may prevent achieving specific acceleration and deceleration values during gripper operation.

The subsequent stage involves the selection of the operating principle of the end effector. Considering the main division of available methods, we can select pneumatic operation, mechanical operation or combined use of several methods of operation.

The initial selection of the operating principle of the gripper is followed by the design stage which entails carrying out the necessary engineering calculations, modeling with CAD tools as well as the necessary kinematics and strength analyses of critical components of the assembly. At this stage, it is necessary to predict the final coupling and joining of the designed components with manipulator assemblies supplied by Binar.
The flexible design and manufacturing algorithm for grippers demonstrates an algorithm for flexible design and manufacturing of customized gripper constructions implemented in Ankotech. The first stage involves a detailed specification of construction and functional features of the object of manipulation/transport. These features include: geometric characteristics, material characteristics and dynamic characteristics. In relation to the gripper design process, the dynamic characteristics are to be understood as the extreme values of force generated by the operated manipulator with gripper. These characteristics are invariably related to the geometric and material characteristics. The surface condition and e.g. strength of the material used in the manipulated object may prevent achieving specific acceleration and deceleration values during gripper operation.

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The next step includes drafting the technical documentation for all components that are not commercially available and preparing it for handover to subcontractors for manufacturing. Moreover, a list of commercially available components is to be drawn up and handed over for purchasing. After receiving all the components, employees may proceed with assembling the gripper. To achieve this, the three main work cell modules should be employed. These can be characterized based on the type and function of works carried out which allows to differentiate a separate module – a station for carrying out tasks related to precision mechanics, die-sinking, modeling. This should allow to machine the fine components of the gripper, carry out mechanical and die-sinking corrections when necessary, and ensure access to the necessary tools when matching and assembling components. The second modular cell should include the necessary tools and
instrumentation for assembling and testing pneumatic systems used by the grippers employing both positive and negative pressure. The third modular cell should allow the installation and handling of the electrical system, electronics and should allow programming the control systems employed in the given gripper construction. The finals stage is to test the assembled construction, carry out all the tests and trial runs followed by commissioning by the ordering party.

4 Examination of coupling parameters for gripping components with the manipulated objects for implementing the first stage of the flexible manufacturing and design algorithm for grippers

4.1 Examination of the variance of force value as a function of change in pressure value in the actuator diaphragm acting as the end effector of the gripper

This chapter presents the results of examination of the frictional force of the cylindrical external surface of the actuator diaphragm on the cylindrical internal surface of the handled object depending on the feed pressure value to the operating chamber of this actuator. To answer the question: why these examinations are relevant from the standpoint of the planned program of experiments? The expanding actuator diaphragm acts as the end effector of the manipulator. Its working characteristics affect the efficiency of gripping and controlling the motion of the object. Therefore, identifying its friction and motion related characteristics will be important. Fig. 5 presents the methodology of the examination.

According to the above drawing, an unfilled actuator diaphragm is first inserted at the specified length into the sleeve (see Fig. 5). After setting the specified value for the supply pressure (these values were equal to: 0.3 MPa, 0.4 MPa, 0.5 MPa and 0.6 MPa), the jet of compressed air is directed through a dedicated connection (see Fig. 4) to the actuator diaphragm. This resulted in the increase in its volume, which effected pressure on the external cylindrical surface of the transported sleeve with the specified force. The examination entailed placing the sleeve-actuator system on the MTS Insight 50 kN strength testing machine, afterwards the strength testing machine was used to apply force value \( F \) to the actuator gripper (see Fig. 5. and Fig. 6). The force was increased until a motion of the actuator diaphragm was effected along the sleeve axis (see Fig. 6). The breakdown point for the force value \( F \) indicated a sudden decrease in its growth (see Fig. 7), this initiated the axial motion of the actuator along the sleeve axis. For every supplied pressure value of the actuator diaphragm, the determination of the characteristic of force \( F \) value variance was repeated three times.

The breakdown point of force value \( F \) (see Fig. 7) can be treated as the point in which the force value \( F \) is starting to exceed the static frictional force value \( T \). This is the determining point for \( F \geq T \) (see Fig. 7). It manifests itself through the initiation of the actuator motion along the axis of the sleeve. In practice, the actuator moves out of the sleeve opening (or

![Fig. 5. The flexible design and manufacturing algorithm for grippers.](image)
another similarly gripped item) and consequently is removed from it. In other words, the maximum value of the static frictional force $T = F$ determines the maximum weight of the transportable item without risk of dropping it. However, one needs to keep in mind that the safety parameter $x$ value needs to be assumed to move away from the boundary value $F \geq T$ (see Fig. 7).

Fig. 6. Experimental study station.

Fig. 7 presents an example characteristic of force $F$ variance depending on the strength testing machine cross-beam displacement for the supplied pressure to the actuator diaphragm equal to $p = 0.3$ MPa.

Fig. 7. Example characteristic of force $F$ variance depending on the strength testing machine cross-beam displacement for the supplied pressure to the actuator diaphragm $p = 0.3$ MPa.

Fig. 8 presents averaged characteristics of force $F$ variance for different pressure values supplied to the actuator diaphragm.
Based on the above characteristics, one can determine the fixing conditions for a given supplied pressure value, weight of the handled item, including the value of the safety parameter \( x \) (see Fig. 7), the value of the safety parameter shall depend on the operating conditions of the gripper (dynamics of motion, trajectory, etc.).

The experimental results were used to develop a simulation model of the diaphragm-sleeve system (see Fig. 9), which can be used in the future to carry out simulations when building grippers with similar end effector solution in form of the pneumatic actuator (see Fig. 3 and Fig. 6).

The elastic actuator sleeve material was represented using the Mooney-Rivlin model \([13]\) with parameters as provided in Table 1 below.
Table 1. Mooney-Rivlin model parameters [13].

<table>
<thead>
<tr>
<th>C_{10} [MPa]</th>
<th>C_{01} [MPa]</th>
<th>D_1</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.7339</td>
<td>-0.000337</td>
<td>1.5828 e-3</td>
</tr>
</tbody>
</table>

Carrying out the series of simulations allowed to determine the graph lines for gripping force variability as a function of displacement of the actuator diaphragm for different values of the coefficient of friction between the diaphragm and internal surface of the cylinder representing the manipulated object (see Fig. 10 and Fig. 11).

Fig. 10. Illustration of the variance of the gripping force of the actuator for different values of the coefficient of friction with the internal pressure value of the elastic actuator diaphragm equal to 0.4 MPa.

Fig. 11. Illustration of the variance of the gripping force value for different values of the coefficient of friction with the internal pressure value of the elastic actuator diaphragm equal to 0.6 MPa.

The above characteristics allow to determine the value of coefficient of friction for the specific supplied pressure value for the elastic actuator diaphragm considering the measured grip force derived in the experimental study discussed earlier.
4.2 Examination of surface contact parameters

As part of implementing the first stage of the algorithm (see Fig. 4), an examination station was developed to determine the value of the coefficient of friction between the manipulated objects (sand-lime bricks), and the material used to make or cover the gripping ends of the gripper. The examination station design was based on a slope (see Fig. 12).

![Image of examination station](image1)

**Fig. 12.** General view of the station to identify the value of the coefficient of friction with objects used for manipulation shown on the right.

Fig. 13 shows the list of example results of the examination.

![Image of friction coefficient values](image2)

**Fig. 13.** List of measured values of the coefficient of friction.

The largest values of the coefficient was identified for samples 1 and 2 contacting PVC material. Whereas the smooth side of the PVC material was characterized by high adhesion, consequently the coefficient of friction value in contact with this surface and the surface of samples 1 and 2 achieved the highest value.

In practice, to increase the safety coefficient to ensure stable contact of the gripper ends, one can consider covering the gripper ends with the material of this type.

The value of the coefficient of friction is reduced by approx. 20% when the sample surface contacts the rough surface of the PVC material. This surface type was characterized by lower adhesion and the rough structure allowed for a smaller area of contact.
In the case of samples 1 and 2 contacting a polyurethane material, the values of the coefficient of friction were equal to approx. $\mu = 0.85$ with sample 1 placed lengthwise and $\mu = 0.95$ with sample 2 placed lengthwise. Crosswise sample placement caused a slight decrease in the parameter value.

In the case of sample 1 contacting natural rubber material, the coefficient value increased close to 1 (for lengthwise placement). In the case of sample 2, the coefficient of friction value reduced significantly, achieving the value of $\mu = 0.71$.

Crosswise placement of samples contacting natural rubber material only slightly affected the coefficient of friction value.

The carried out examinations indicate that the direction of placement of sample materials 1 and 2 slightly affected the coefficient of friction values. Covering the gripper ends with a layer of PVC, polyurethane or natural rubber allows to increase the coefficient of friction, positively affecting the security of grip of the handled item.

The surface of the material also affects the value of the coefficient of friction. Smooth, adhesive PVC surface resulted in the higher measured coefficient of friction value in comparison to the rough PVC surface. The polyurethane and natural rubber surfaces were also rough.

### 4.3 Simulation studies of the gripper construction

Determining the gripper strength – apart from experimental studies, when designing new construction of specialized gripper units, CAD tools prove to be useful. The chosen software package may assist the designed at the modeling stage and inspecting the motion kinematics of gripper components (see Fig. 14). Moreover, with the employment of such software, it is possible to quickly perform strength analyses for different kinematic configurations of grippers.

![Fig. 14. General view of real model and virtual model of the gripper.](image)

Simulation of kinematics and strength of the gripper for axisymmetric pipe-like items was carried out for pipe weight range $s_m = 10 - 100$ kg and diameters: Ø70 mm, Ø90 mm, Ø110 mm, Ø130 mm, and Ø145 mm. Fig. 15 presents an example stress distribution when gripping a Ø90 mm diameter pipe with respective weight of 10 kg and 100 kg.
Performing the analyses described above allowed to identify the characteristics of stress value variance as a function of weight and diameter of the handled object (see Fig. 16).

According to the above graph, object weight and not the diameter has a material effect on the resulting stress value.

**5 Conclusions**

The Flexible Manufacturing System should allow to introduce changes and improvements in a very short time at every stage of the manufacturing process. Only such an approach allows for the end product to meet all the design specifications indicated prior to the building process. Single-item manufacturing of highly specialized gripper constructions necessitates that works are divided into three groups: high precision mechanical processing and modeling, pneumatic system works (also hydraulic system works, if so required in the future) as well as electrical system/electronics with programming. A quick transition from a virtual model to prototype on one of the two modular stations dedicated to fast prototyping allows to accelerate the design process at the same time maintaining high product quality and reducing costs of manufacturing.
Fig. 15. Equivalent stress distribution in grip per components: a) m=10 kg, d=Ø90 mm, b) m=100 kg, d=Ø90 mm.

Performing the analyses described above allowed to identify the characteristics of stress value variance as a function of weight and diameter of the handled object (see Fig. 16).

Fig. 16. The maximum stress values in gripper components as a function of the weight of the handled item (10-100 kg) and its diameter.

According to the above graph, object weight and not the diameter has a material effect on the resulting stress value.

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References