Automated generation of adapter plates for industrial robots

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Abstract. The current market offers a wide range of different robots and end effectors from a variety of manufacturers and in different versions, where the mechanical compatibility between the components has to be ensured. A large part of the flange patterns of the end effectors offered are not designed to conform to standards, which is one of the reasons why adapter plates must be used to ensure compatibility. Particularly in the early phases of engineering, the weight of the adapter plate and the extension of accessibility can be taken into account in the robot configuration when generating an adapter plate. In order to enable the generation of an adapter plate as early as possible, automated generation offers a great advantage and can contribute to the reduction of engineering effort and thus to time savings and cost reduction. This paper describes a general design rule for the generation of adapter plates and, on this basis, implements the generation of CAD geometries of the adapter plates using Constructive Solid Geometry. The results of this paper are the starting point for the implementation of a web service, which will be integrated into the ROBOTOP project.

Keywords: Flange patterns, construction instruction, Constructive Solid Geometry.

1 Introduction

Industrial robots and end effectors are offered by a large number of manufacturers and in an abundance of design variants. For example, 422,271 robots were delivered worldwide in 2018, which represents an increase of 15 percent over the previous year. Similar figures are predicted for 2019. [1]. The market situation for end effectors is similar, with the four best-selling end effectors manufacturers alone (Schunk, Schmalz, Destaco and Festo) currently offering over 5,400 different grippers [2-5]. In order to ensure compatibility between the individual components across manufacturers, the interfaces between robot arms and end effectors must be clearly defined. This should make it easier for the customer to configure robot systems and ensure a lower knowledge barrier for the combination of different robot solutions. Small and medium-sized enterprises (SMEs) in particular can be supported by this in production automation. Because of its relatively low degree of automation, the SME market offers a particularly high potential for future

automation through robot systems. Decisive factors with the implementation of such robot systems are the high engineering expenditure and the high costs. Thus, many robot solutions cannot be economically represented for system integrators up-to-date or only to a very limited extent.

The ROBOTOP project addresses this problem by developing an online configurator for robot systems. Within the scope of this research project, the mechanical interfaces of the end effectors and robot arms are considered. If the components to be assembled have different flange designs, they have to be brought together with an adapter plate. In addition to bringing the flange patterns together, the adapter plate also offers the possibility of changing the offset position of the end effector on the robot system. Thus, on the one hand, the end effector can be realized in the extension of the axis of the robot, a lateral offset or a rotation of the end effector is also possible. The generation of these adapter plates is currently carried out mainly by the manufacturers when the end effectors are delivered or by the customer himself. Here, the development of special adapter plate shapes is combined with relatively high effort and is not based on any standardized process. Due to the design of the adapter plates from quantity one at the customers themselves, the adapter plates are usually oversized for safety reasons. This leads to an overall higher dead weight of the adapter plate and thus to a reduction of the possible payload of the robot. In addition, the increase in reachability due to the offset of the end effector with the help of the adapter plate is often not used at all or only in the later phases of the planning process. Thus, the generation of an adapter plate at the time of the configuration of the robot system would allow a reduction of the engineering effort and an optimization of the robot system selection during the planning of the robot system.

Within the scope of the ROBOTOP research project, the generation of the adapter plate is to be automated. This process has to be standardized. A generally valid procedure for the generation of an adapter plate is described in this paper and a type code developed for this purpose is listed.

2 Flange patterns

In order to ensure the compatibility between the flange designs and to guarantee the implementation of the robot systems across manufacturers, the interfaces must be standardised and associated standardisation introduced. If one considers the standardisation situation in the area of robot flanges, ISO ISO 9409 - 1, ISO 9409 - 2 and DIN ISO 29262 should be mentioned here[6-8].

ISO 9409 - 1, published in 2004, forms an important basis for ensuring the interchangeability of manually mounted end effectors in the form of round mechanical interfaces. The application of this standard is not only limited to industrial robots, but can also be applied to hand lifting devices such as insertion devices, manipulators or teleoperators. Here decisive characteristic values (among other things type and number of thread and fixing holes, diameter specifications) are defined, which allow a holistic description of the flange patterns.

The second part of the DIN ISO standard 9409 defines the main dimensions, the designation and the marking of shafts of the mechanical interfaces of industrial robots.

In contrast to ISO 9409 - 1, the ISO 9409 - 2 is designed for relatively low load capacities and is suitable for applications in which end effectors move in small gaps. Furthermore, DIN ISO 29262 defines microscopic interfaces for end-effectors and handling equipment in the field of micro and precision engineering. In addition to the mechanical interface, the position and classification of electrical and fluidic coupling elements is also included.

A closer look at the robot systems available on the market reveals that the ISO 9409-2 and DIN ISO 29262 standards are rarely used. This could primarily be due to the fact that the market for robots with such low load capacities serves a niche in which special designs are used for the respective application, in which the adaptation to the respective robot flange does not represent a large additional expenditure.

On the other hand, the ISO 9409-1 standard is widely used. Studies of LPS carried out that about 81% of all flanges of the seven largest robot manufacturers (ABB, Kuka, YAMAHA, Denso, Kawasaki, Mitsubishi and Yasakawa) are designed according to this standard. Thus, a relatively high degree of standardization can be observed here. The situation is different for the end effectors. A look at the five largest manufacturers (SCHUNK, Schmalz, Destaco, Festo and FeRobotics) shows that only 21 % of the end effectors comply with the standard.

It is noticeable that the Cobot gripper flanges in particular exhibit a very high degree of standardization. Reasons for this could be, among others, the fundamentally higher degree of standardization in the area of human-robot collaboration, the increased safety requirements and a higher requirement for weight and design, which does not permit an additional adapter plate, which would mean additional weight.

In conclusion, it can be said that only ISO 9409-1 is used in industry. This standard is mainly used in the area of robot arm flanges, but only to a small extent for end effectors. Furthermore, this standard only defines round flange patterns, where rectangular flange patterns are also available in significant numbers on the market. This means that there is neither a generally valid description of robot flanges nor does it consistently comply with the existing standards. As a result, there is an inconsistent image on robot flanges, both on the robot side and on the end effector side. Thus, adapter plates are still an important tool in the field of robotics to connect these components with each other. At the same time, it becomes clear that for efficient and automated generation, a clear design rule must be generated.

3 Automated adapter plate generation

Within the scope of ROBOTOP it is necessary to be able to offer a total solution of a robot system for the customer, whereby primarily industrial robot solutions were concentrated, which cover small to medium sized payloads. The weight of the adapter plate as well as the extension of the accessibility by the adapter plate should already be considered in the design of the robot system. Thus, the feasibility of the robot system can be better validated at a very early stage, which leads to a reduction in the engineering effort and thus to a shortening of the implementation times of the system.

The basic procedure for generating an adapter plate is shown in Fig. 1. Here it is first necessary to select a robot system according to the requirements of the SME. The ROBOTOP configurator can be used for this purpose, for example. Then the flange

images have to be defined. Here the contact surfaces of the flange and the boron extinguishers for fixing the adapter plate or the end effector have to be defined. The information can be taken either from construction drawings, CAD models or, in the case of standardized flange pictures, from the product description. This step decides whether or not an adapter plate is required for compatibility of the selected components. In preparation for generating the adapter plate, the requirements for the adapter plate must be defined. Afterwards the automated generation of the adapter plate can be performed. An iteration then searches for a new selection of the robot system and repeats the generation process. Finally, an optimized selection of possible robot system configurations is suggested. In this paper we will concentrate on steps two to four.

Fig. 1. Procedure for iterative adapter plate generation.

There is currently no standardization and no tool that would describe or implement the generation of adapter plates. In order to be able to offer an efficient solution for manufacturer-independent and non-standard flange designs, a clear definition of the construction instruction for adapter plates is necessary. Building on this, the corresponding geometry can now be generated using Constructive Solid Geometry.

3.1 Design specification for the generation of adapter plates

The unique construction instruction forms the basis for the effective and automated generation of an adapter plate. As already mentioned, there is currently no standardization in this area that could be used for this purpose, so it is necessary to define this design rule. A generally valid definition was made in the context of the research work on the LPS, from which the type code shown in Figure 1 results. In this case, adapter plates that connect a robot arm with a gripper were initially used. Furthermore, additional kinematics or sensors in the adapter plate were not considered.

Each adapter plate consists of two or more flanges which have drilled holes for mounting and a structure for connecting these flanges. Optional feedthroughs or brackets for power and information interfaces can be attached to the worktop. All the relevant parameters are briefly listed below.

Fig. 2. Construction instruction for adapter plate.

Flange patterns can be categorised as round or rectangular. This is primarily determined by the parameter F. The next step is to define the boreholes, so these are first to be defined in the number (A) and their arrangement on the flange plate (N). Depending on the arrangement, the position and diameter of the holes must then be specified (B, T, A). Thus the flange patterns are defined holistically, whereby now the position and orientation of these to each other must be determined (X, Y, Z, RX, RY, RZ). In order to connect these flange patterns, the characteristics of the structure (S) and the course of the connecting structure in space (X, Y, L) must now be determined. This makes it possible to define the connection structure in such a way that interfering contours which the area of application of the robot entails are taken into account, thus extending the accessibility and versatility of use for parts which are difficult to access. Finally, the type (V) and positioning (P) of the required energy and information interfaces must be defined. A database with conventional power connectors and hydraulic connections is used for this purpose. When positioning, the user only defines the side of the position of the connections. The exact positioning and the required holes or grooves for fastening these holders or bushings are set automatically. Defined space requirements on all sides of the plugs or holders are defined by boarding boxes.

3.2 Generation of geometric flanges using constructive solid geometry

In order to compute appropriate geometries, we introduce parametric geometries. For this, we define an XML syntax that allows the specification of constructive solid geometries. The syntax specifies three different kinds of objects: solids, mathematical operations, and loops.

Solids are defined by a region within the x/y-plane and an extrude operation. By now, we have two operations implemented. The first one extrudes the specified region linearly in z-direction. The second one revolves the region around the x-axis. In addition, any solid can be moved and rotated arbitrary in space.

Based on the solids, we can create more complex geometries by using mathematical operations. Merge operations are used to combine two or more solids to a single one. Subtract operations will remove one or more solid from another one.

Loops can repeat both solid creation and mathematical operations with a given number of times. An accumulating transformation specifies a relative offset for each interaction step.

```
<?xml version="1.0"?>
<ParametricXML xmlns:xsi=http://www.w3.org/2001/XMLSchema-instance
  xmlns:xsd="http://www.w3.org/2001/XMLSchema">
  <Parameters>
    <Parameter Name="Radius" Symbol="R" Value="100"/>
    <Parameter Name="HolePositionRadius" Symbol="R1" Value="80"/>
    <Parameter Name="NumberOfHoles" Symbol="N" Value="6"/>
  </Parameters>
  <Difference>
    <Color Value="#008800" />
    <Extrude Length="20">
      <Path StartX="-{R}" StartY="0">
        <ArcTo X="{R}" Y="0" CenterX="0" CenterY="0" ClockWise="false" />
        <ArcTo X="-{R}" Y="0" CenterX="0" CenterY="0" ClockWise="false" />
      </Path>
    </Extrude>
    <Loop Count="{N}">
      <Displacement RZ="360/{N}" />
      <Union>
        <Extrude Length="10">
          <Transform X="{R1}" />
          <Path StartX="-5" StartY="0">
            <ArcTo X="5" Y="0" CenterX="0" CenterY="0" ClockWise="false" />
            <ArcTo X="-5" Y="0" CenterX="0" CenterY="0" ClockWise="false" />
          </Path>
        </Extrude>
        <Extrude Length="10">
          <Transform X="{R1}" Z="10" />
          <Path StartX="-10" StartY="0">
            <ArcTo X="10" Y="0" CenterX="0" CenterY="0" ClockWise="false" />
            <ArcTo X="-10" Y="0" CenterX="0" CenterY="0" ClockWise="false" />
          </Path>
        </Extrude>
      </Union>
    </Loop>
  </Difference>
</ParametricXML>
```

Fig. 3. XML example for a parametric flange.

Fig. 4. Image of the geometry specified by the XML document depicted in **Fig. 3**.

For all three kinds of objects, parameters can be specified. Hence, we can define a parameter-based template for various geometries. By changing the parameters, we can influence the shape in a simple manner. Of course, there are constraints in the construction possibilities. The drawing plane for new regions is always the x/y -plane, for instance. However, the specification is made with respect to simplify the parsing and computation.

Fig. 3 shows an example for a simple flange. A web-service accepts the document and computes the geometry. We have implemented various export options, e.g. STEP, JSON geometry format, and 3D view embedded within an HTML document. Fig. 4 shows the computed geometry.

Fig. 5. Image of a complex adapter plate geometry

With the web-service, besides such relatively simple geometries, almost all possible geometric forms are conceivable. The potential of the service is demonstrated by the exemplarily generated geometry in Fig. 5. This adapter plate should connect a gripper with a rectangular flange and a robot with a round flange. This flange, with its extension and angulation, serves to keep the relatively thick flange geometry of the robot further away from the poorly accessible handling position. This means that greater accessibility can be achieved even in confined spaces. The parametrisation happened via the XML schema described above.

In the future, the parameterization will be extended by a user interface, so that the XML schema is generated in the background. The aim is to guide the client through a user centred configuration process that is as simple as possible.

In addition to the generation of adapter plates, the web service is so generically structured that it can also be used for the generation of various geometries in the sense of a micro service architecture. Overall it is currently used to generate simple workpieces on the ROBOTOP platform[9-10].

Furthermore, optimization potential was seen in the geometry of the adapter plates of low stressed areas, which are to be generated in the future on the basis of the finite element structure synthesis.

4 Results

In conclusion, an early automated generation of adapter plates reduces the engineering effort and enables the consideration of this adapter plate already in the early planning phase of a robot system. In this context, the dead weight and the extension of the accessibility of the robot can play an important role in the design of the system.

An automated generation of such adapter plates was implemented as an example.

In the case of automated generation, a generally valid description of these plates and thus also of the flange images is necessary. At present, however, such standardisation is lacking in the areas of robot flanges, gripper flanges and adapter plates. A generally valid design specification for robot adapter plates was developed in the context of this paper. For the generation of the CAD geometry, an automated generation was realised on the basis of the developed construction regulation, medium Constructive Solid Geometry. Here the developed web-service is fed by means of an XML based syntax and allows an almost unlimited free space in the geometry design.

In this context we were able to prove, that the developed design rule for the definition of an extended adapter plate is working well. The generation via CSG turned out to be practicable.

The parameterisation of the adapter plate is to be extended in the future, by a specially developed user-centred interface and then integrated into the ROBOTOP platform.

Momentarily, the optimisation of the adapter plate geometries still poses a difficulty, here a finite element structure synthesis could be carried out with the aim of reducing the weight of the adapter plate.

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