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Simulation of the behavior of pneumatic drives for virtual commissioning of automated assembly systems

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ABSTRACT

Nowadays the development of complex automated assembly systems is almost impossible without the support of computer aided simulation methods. In order to increase the reliability of such simulations, the simulation models must depict the realistic, physically correct behavior of the assembly system. Thus, including the physical properties of the elements in the models allows for an increase in realism of the simulation. One of the challenging aspects in this field is the physical behavior of pneumatic drives. For simulating the correct pneumatic behavior in the validation procedure virtual commissioning, the simulation model must further meet real-time requirements. In this contribution a simulation model for the pneumatic behavior that can be used in virtual commissioning is presented. Physics based simulation capabilities based on game engine technology are applied, complemented by physics based modeling using thermodynamic laws. Additionally, the simulation model is quantitatively validated in terms of accuracy with respect to kinematics, dynamics, and compressed air consumption.

1. Introduction

The automated realization of assembly processes is becoming more important for the cost effective production of manufacturing companies [14]. A rising number of new product variants must be seamlessly integrated into running production processes while guaranteeing high output quality For these companies the increasing number of new product variants [15] which are manufactured in parallel to the existing product variants by the same automated assembly system represents a new challenge in which the quality of the produced goods needs to be guaranteed at all times [15] (cf. Fig. 1). In order to cope with this challenge, companies' production planning departments rely on simulation models for validating the functionalities of automated assembly systems in early stages of the development process [15].

One well established virtual validation methods widely discussed among practitioners and within academia is virtual commissioning. For raising acceptance of virtual commissioning the simulation models need to be optimized in order to represent the realistic system behavior to the greatest possible extent [9]. One possibility for doing so is to include physical system characteristics into those simulation models. Several approaches demonstrate how physical characteristics can be included when analyzing the behavior of the entire assembly system [2,16]. Correct physical behavior in terms of kinematics and dynamics of the system components are of paramount importance and in particular the physical behavior of drives is one of the main concerns for virtual commissioning. In general, these actuators are used to accomplish precise movements of the assembly components and products, respectively. Both electrical and pneumatic actuators, e.g. electrical motors or pneumatic cylinders, are essentially used in automated assembly systems. This contribution focuses on pneumatic actuators firstly introducing physical fundamentals of pneumatics, secondly introducing a prototypical implementation of the physics based simulation model for virtual commissioning, and thirdly presenting its validation considering kinematics, dynamics, and compressed air consumption.

2. Mechanical analysis of pneumatic drives

For the movement of automated assembly system components pneumatic actuators are often implemented. Linear as well as rotational movements of components or products can be simply realized by the use of pneumatic actuators [10]. The controlled inflow of compressed air into the pneumatic cylinder entails the kinematic and dynamic behavior of the actuator, such as force and speed of the piston. Forces and torques originating from the assembly components also influence the physical behavior of pneumatic drives. As a consequence the assembly components'

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forces and torques considerably determine the speed of the pneumatic drive and hereby also the duration of the assembly process. Fig. 2 displays the forces of a pneumatic actuator in a schematic manner.

When solving the equilibrium equation of the forces which act along the x-axis the acceleration $\ddot{X}$ against the extrinsic power F_K can be determined.

$$\ddot{x} = \frac{F_{A2} - F_{A1} - F_K - F_F}{m} \quad (1)$$

In order to move the piston along the positive x-axis the condition $F_{A2} > F_{A1} + F_K + F_R$ must be fulfilled. Assuming an increase of the extrinsic force F_K, provided that F_{A2}, F_{A1} and F_R keeping their original values, the piston's acceleration $\ddot{x}$ and therefore its speed $\dot{x}$ would decrease (Eq. (1)). For the improvement of virtual commissioning the extrinsic force F_K must be estimated that depends

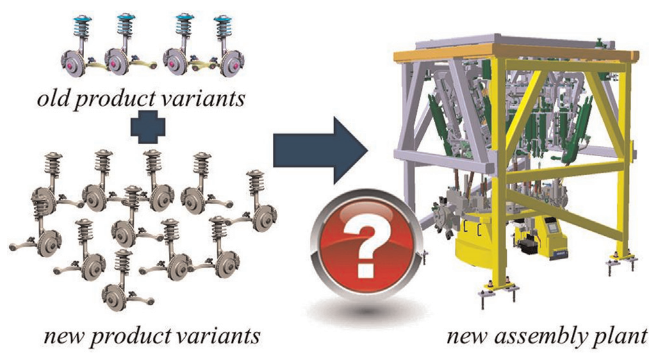


Fig. 1. Integrating new product variants in a new assembly system.

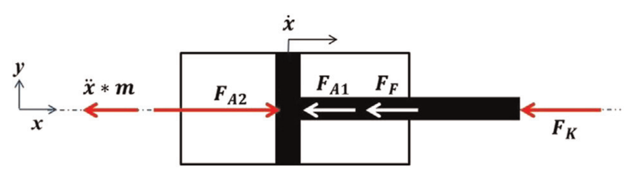
on the dynamics of the system components and further affects directly the piston's speed and so the duration of the piston's movement.

Usually, the forces F_{A1} and F_{A2} are assumed to remain constant. In reality these forces depend linearly on the chamber pressure [11]. Furthermore, the air in the chambers is compressible, thus the pressure in the chamber cannot be constant [10,11]. Here, the extrinsic force F_K plays a fundamental role on the air pressure in each chamber. Based on that the acting forces and so the physical behavior of the assembly system components would also need to be considered during virtual commissioning.

In virtual commissioning of automated assembly systems those influencing factors are currently not considered. Normally, a constant speed is assumed and therefore the duration of the movement is pre-defined in the first place. This assumption limits the validity of the simulation model and hinders early detection of errors that can be attributed to the physical behavior of pneumatics drives. One representative error is a designated position that cannot be accessed by the pneumatic drive due to unforeseen changes of the extrinsic force.

3. Theoretical foundations for physics-based modeling of pneumatic drives

For simulating the correct physical behavior of pneumatic drives basic physical laws of fluid mechanics must be considered. This chapter presents the basic laws of fluid mechanics that are implemented in the physics-based pneumatic model and further introduces the common industrial usage of pneumatic drives in automated assembly systems.



$\ddot{x}$ - *Piston acceleration*

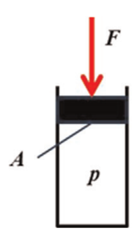
m - *Piston mass*

F_F - *Force due to friction between piston and cylinder*

F_K - *Extrinsic force based on the assembly components acting on the piston*

$F_{A1/A2}$ - *Force resulting from the air pressure in both chambers (A1 – right, A2 – left)*

Fig. 2. Forces acting on the piston of a pneumatic drive.



$$p \cdot V = m \cdot R \cdot T \quad (2)$$

$$p = \frac{F}{A} \quad (3)$$

m - *Air mass*

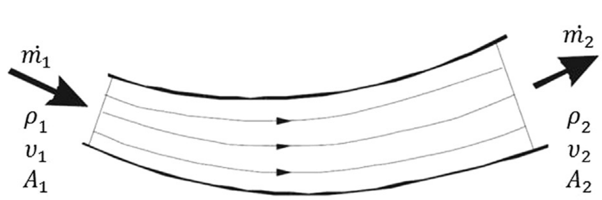
R - *Universal gas constant*

p - *Air pressure in the system*

F - *Extrinsic force acting on the piston*

A - *Area of the piston*

Fig. 3. Fundamental equations of fluid mechanics.



$$\int_A \rho \cdot v \cdot dA + \frac{d}{dt}\int_V \rho \cdot dV = 0 \quad (4)$$

$$\dot{m}_1 = \rho_1 \cdot v_1 \cdot A_1 \quad (5)$$

$$\dot{m}_2 = \rho_2 \cdot v_2 \cdot A_2 \quad (6)$$

$$\dot{m}_1 - \dot{m}_2 = 0 \quad (7)$$

Fig. 4. Stationary flow system and corresponding equations [10].

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