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Batch-Oriented Setting Time Optimisation in an Aerodynamic Feeding System

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***Abstract*—**The change of conditions for production companies in high-wage countries is characterized by the globalization of competition and the transition of a supplier´s to a buyer´s market. The companies need to face the challenges of reacting flexibly to these changes. Due to the significant and increasing degree of automation, assembly has become the most expensive production process. Regarding the reduction of production cost, assembly consequently offers a considerable rationalizing potential. Therefore, an aerodynamic feeding system has been developed at the Institute of Production Systems and Logistics (IFA), Leibniz Universitaet Hannover. This system has been enabled to adjust itself by using a genetic algorithm. The longer this genetic algorithm is executed the better is the feeding quality. In this paper, the relation between the system´s setting time and the feeding quality is observed and a function which enables the user to achieve the minimum of the total feeding time is presented.

***Keywords*—**Aerodynamic feeding system, batch size, optimisation, setting time.

I. Introduction

PROCEEDING changes of market cause modified requirements to modern production business and changing target variables to their production systems. In respect of Deutschmann this modified requirements can directly be transferred into individual elements of a production system and also be applied in a high extent to the feeding technology [1]. More frequent product changeovers in series production necessitate neutral feeding technologies without the need of retooling for different components [2]. In practice, this desire cannot be realized due to the complexity of feeding operations and a wide range of components to be fed [3]. As a result of this, many retooling operations are required at the attendant feeding technology. Consequently, the need for flexibility of feeding systems is addressed in [4]-[6]. To achieve this flexibility, feeding systems need to be designed and constructed for adaption with minimal setup effort and in particular within short setting time to new components [4]. As part of these requirements an aerodynamic feeding system has been developed by the Institute of Production Systems and Logistics (IFA) at the Leibniz Universitaet Hannover. Due to the potential in terms of feeding speed, variant neutrality and reliability, this process is a very flexible alternative to conventional feeding technology [7]. The aerodynamic feeding equipment gets workpieces in a desired orientation by using air streams and asymmetric workpiece characteristics. For example, this can be an asymmetric centre of gravity, locally differing flow resistances or asymmetrically projected forms [8]. Retooling of the feeding system is limited to the adaption of only four machine parameters [8]. Since the manual adjustment of these parameters is very time consuming and requires a high expert knowledge, a genetic algorithm has been developed and validated in a simulation environment. This algorithm enables the feeding system to automatically identify the optimal parameter configuration [9]. Before implementing the genetic algorithm into the control unit of the real-life feeding system, in this paper, it is presented how many workpieces have to be inspected during the initial setting of the feeding system depending on the total amount of workpieces to be fed. In particular, the trade-off between the duration of the parametrisation of the feeding system and the feeding quality is focused.

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II. Requirements of Modern Feeding Systems

Another target variable besides the need of flexibility is the feeding system´s applicability on a wide range of different workpiece geometries [1]. This includes also the requirement to enable feeding systems to orient workpieces based on minor workpiece characteristics [5].

Due to decreasing product life cycles, even in mass production a production system needs to be able to produce large quantities in a short time [10]. The rise of product changes leads to frequent product ramp-ups – as well as in the attendant feeding systems. In the context of production ramp-ups, Heins et al. refer to the effectiveness target to enable high production outputs while operating at the highest possible quality rate in series production [11]. Hoehne et al. concretise this request for the assembly with the necessity of feeding rates of at least 1,000 parts per minute [12]. Furthermore, Nyhuis et al. claim a fast realisation of series production after production ramp-up [13]. Consequently, target variables of feeding processes can be differentiated between a high feeding efficiency in steady operation and fast realization of this feeding efficiency after product changeovers.

III. Analysis of the Influence of the Workpiece Quantity to Identify the Optimal Parameter Setting

A. Simulation-Based Analysis

A key factor for the simulation-based determination of

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optimal setting parameters is the number of simulated workpieces. The larger this number is chosen, the more significant are the simulation results and the higher is the quality of these results; but the longer is the simulation time. Therefore, in this section the correlation between the number of simulated workpieces and the resulting quality is analysed. In order to determine this correlation, the simulation is performed several times, each with a different number of simulated workpieces for a fixed parameter setting of the feeding system and thereby the resulting orientation rate is investigated. The parameter values of α, β, p, and v are chosen in a way that led to an orientation rate of 90.1% at the real-life feeding system. The simulation is performed for simulated workpiece numbers of $j_S = 10, 20, \ldots, 100, 200, \ldots, 500$ each with 100 simulation cycles. The average, minimum and maximum orientation rates can be determined from the simulation data for each simulated workpiece number j_S. Thereby, the three best and three worst orientation rates are not considered in the analysis in order to decrease the influence of extreme values on the distribution of measured values. The corresponding evaluation of orientation rates is shown in Table I.

TABLE I
REPRESENTATION OF THE AVERAGE, MINIMUM AND MAXIMUM ORIENTATION RATES DEPENDENT ON SIMULATED WORKPIECE NUMBER

Number of simulated workpieces j_S	With a 95% - Confidence Interval		
	Average Orientation Rate / %	Maximum Orientation Rate / %	Minimum Orientation Rate / %
10	91.33	100.00	80.00
20	91.57	97.50	82.50
30	90.90	95.00	83.33
40	90.69	95.00	85.00
50	90.67	96.00	86.00
60	90.48	95.00	85.83
70	89.80	94.29	85.71
80	90.84	94.38	86.88
90	90.69	93.89	86.67
100	90.28	93.50	87.00
200	90.45	93.50	88.50
300	90.68	93.00	88.50
400	90.51	92.25	88.38
500	90.56	92.00	88.80

In the next step, regression curves of the discrete measurements of Table I are determined, approaching the average, maximum and minimum orientation rates. The average orientation rate O_{ave} can be approximated by the following linear equation:

$$O_{ave} = -0.00047 * j_S + 90.682 \quad (1)$$

The approximation of the maximum orientation rate O_{max} is performed with a function, which is composed of the addition of a logarithmic curve and a straight line equation.

$$O_{max} = 102.43 * {j_S}^{-0.018} + 0.001 * j_S \quad (2)$$

For the approximation of the minimum orientation rate O_{min} a C_{Norm}-function is selected and added at a constant rate. This results in the following functional equation:

$$O_{min} = \sqrt[10]{88.9^{10} - (88.9 - 0.2225 * j_S)^{10}} + 0.002 * j_S - 1 \quad (3)$$

Fig. 1 illustrates the distribution of the determined average, maximum and minimum orientation rates and shows the course of the regression curves derived in the upper portion. It is shown that with an increasing number of workpieces j_S the determined maximum orientation rate declines strongly at the beginning, slightly declines at a later stage and steadily approximates to the average orientation rate. The determined minimum orientation rate behaves similarly. With an increasing number of simulated workpieces it approximates strongly at first, before it approximates slightly to the average orientation rate after more than 100 simulation parts j_S. Thus, the scattering of the simulated orientation rates represents the key factor for the results quality; it also determines the optimal number of simulated workpieces. It is calculated in the following step. For the scattering of orientation rate $O_{scattering}$ is valid:

$$O_{scattering} = O_{max} - O_{min} \quad (4)$$

That results in the graph shown in Fig. 2 and it is shown that with an increasing number of simulation parts the scattering of the orientation rate sharply declines in the range of $j_S = 10$ to $j_S = 50$. From a number of 50 parts the decrease of the scattering gradually reduces. To illustrate the diminishing decrease of the scattering with an increasing number of simulation parts, the derivation of the scattering is formed. This is shown in Fig. 3.

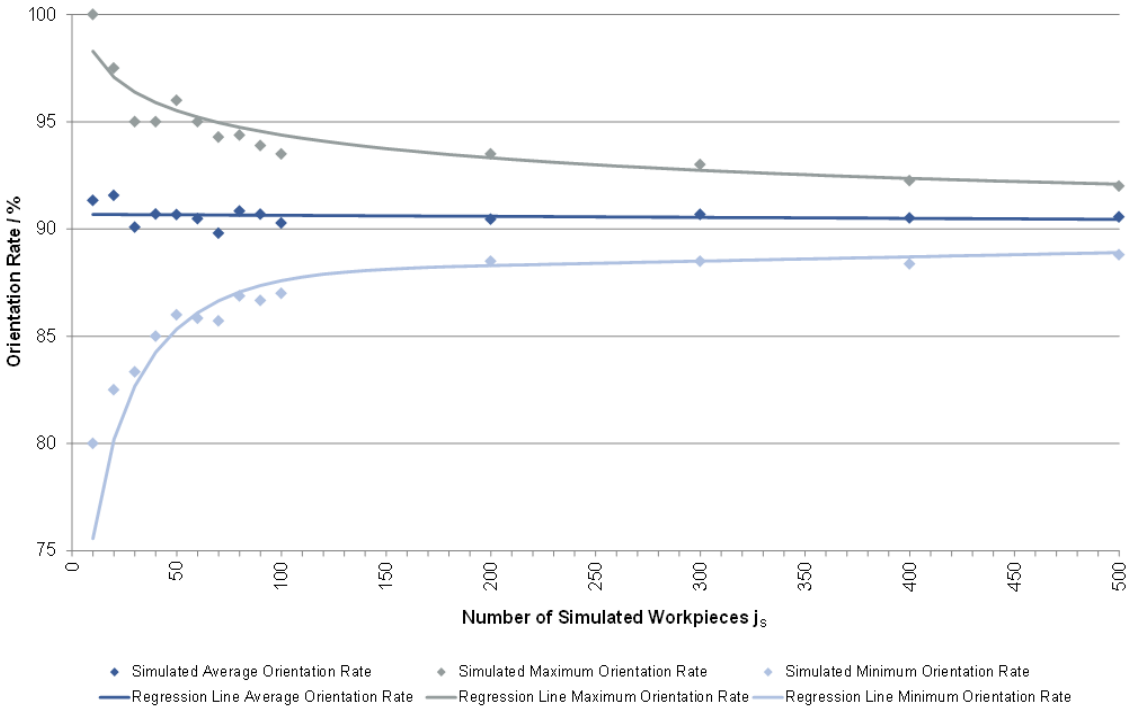


Fig. 1 Correlation between orientation rate and number of simulated workpieces

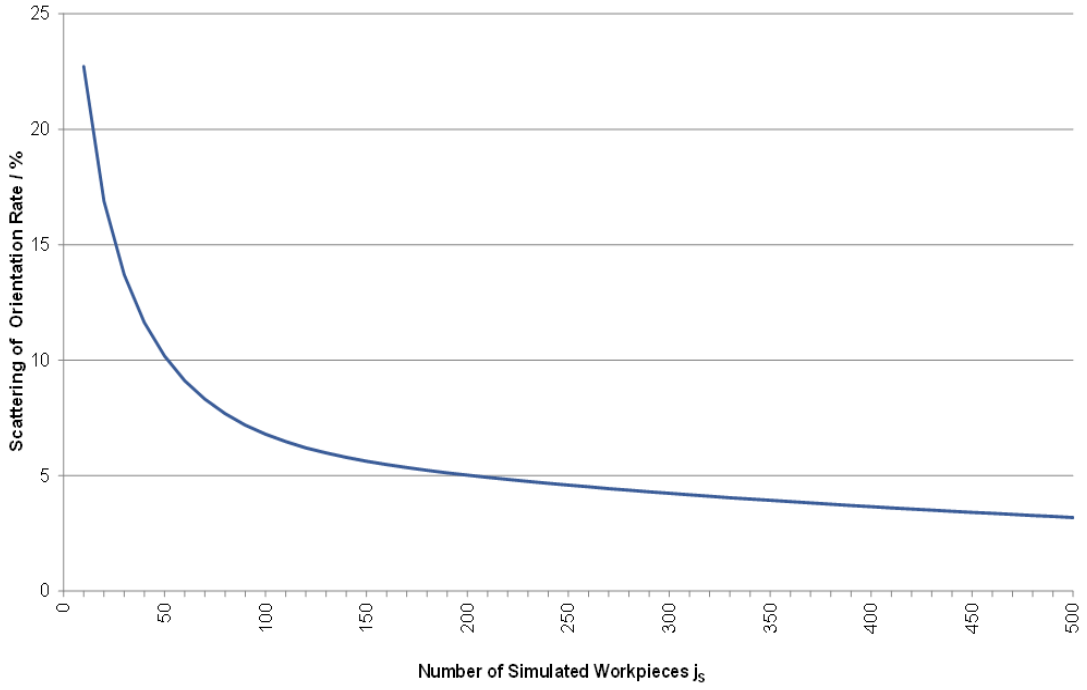


Fig. 2 Scattering of orientation rate dependent on number of simulated workpieces

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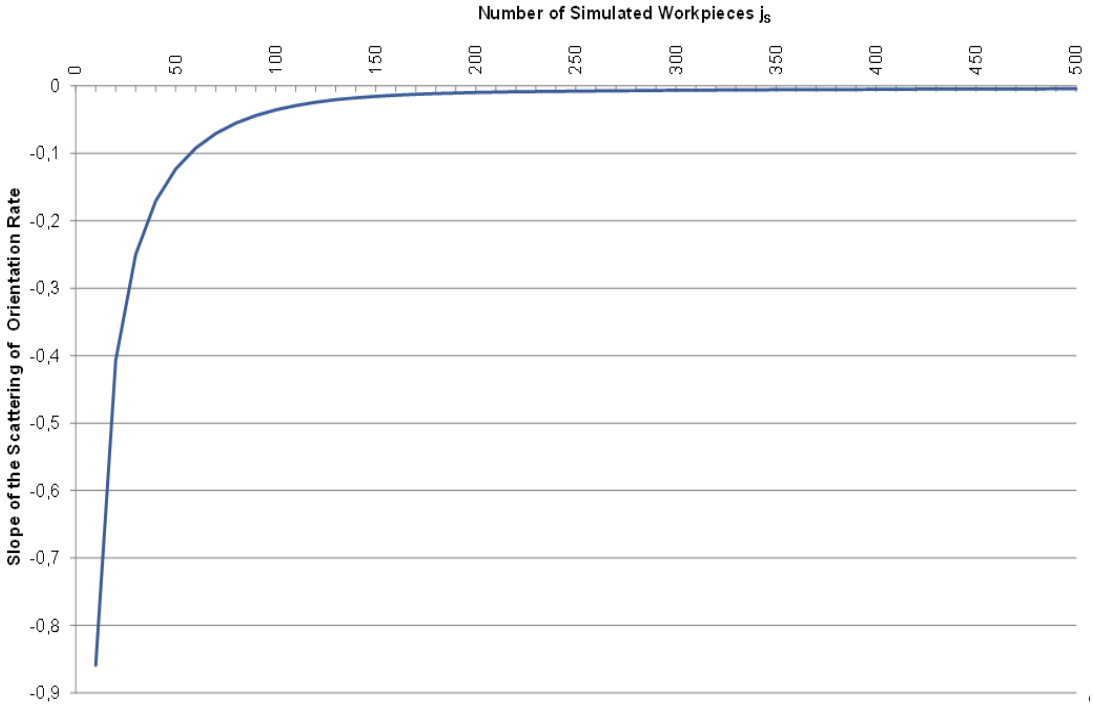


Fig. 3 Slope of the scattering of orientation rate dependent on the number of simulated workpieces

B. Transferring the Simulation Results into a Real Feeding Process

Once the ideal number of simulated workpieces is determined as in the previous section III-A, the optimal number of workpieces j should be derived for setting the feeding system of a real feeding process in this section. The total feeding time of a batch t_{batch} is the key factor to be optimized in this consideration. It is composed by the setting time $t_{setting}$ of the feeding system and the duration for the following feeding process $t_{feeding\text{-}process}$. The duration of the subsequent feeding process depends on the setting time so far, as that faster setting times lead to poor orientation rates in average and consequently reduce the number of fed workpieces. Conversely, long setting times lead to higher orientation rates in average, which cause the required number of correctly oriented workpieces is reached more quickly. The setting time of the feeding system depends on the pace of the genetic algorithm's convergence. A key factor, that affects the pace of the convergence significantly, is the number of individuals $n_{individual}$ needed for a very good solution and generated by the genetic algorithm. The duration per individual results from the division of the workpieces number j and the feeding rate Z. For new parameter configurations to be evaluated, the setting time of the feeding system can be neglected as a simplification, because in proportion to the test duration, this time is nominally. Therefore, the setting duration for new components is applied as:

$$t_{setting} = n_{individual} * \frac{j}{Z} \tag{5}$$

The duration of the feeding process t_p is calculated from the parameters of the total quantity of workpieces to be supplied L, the feeding rate Z and the actual orientation rate O_{actual}. This can be seen in following correlation:

$$t_p = \frac{L}{O_{actual} * Z} \tag{6}$$

For the derivation of the actual orientation rate, it is assumed that the regression graphs obtained in the previous section III-A for the mean, minimum and maximum orientation rate as well as the scattering of the orientation rate can be transferred to the real setting process. Furthermore, it is assumed that the actual orientation rate corresponds to the average orientation rate of the simulation. Following equation arises for the actual orientation rate:

$$O_{actual} = O_{abort} - \frac{O_{scattering}}{2} \tag{7}$$

For the total feeding time of a batch following correlation arises:

$$t_{batch} = n_{individual} * \frac{j}{Z} + \frac{L}{\left(O_{abort} - \frac{O_{scattering}}{2}\right) * Z} \tag{8}$$

To illustrate this correlation, the total feeding time depending on the number of workpieces and batch sizes is illustrated in Fig. 4. Thereby, it is assumed that $Z = 550$ parts/minute and $O_{abort} = 95\%$. Former research activities have also shown that the number of individuals $n_{individual}$ to be tested for reaching the abort orientation rate of 95% is 31.

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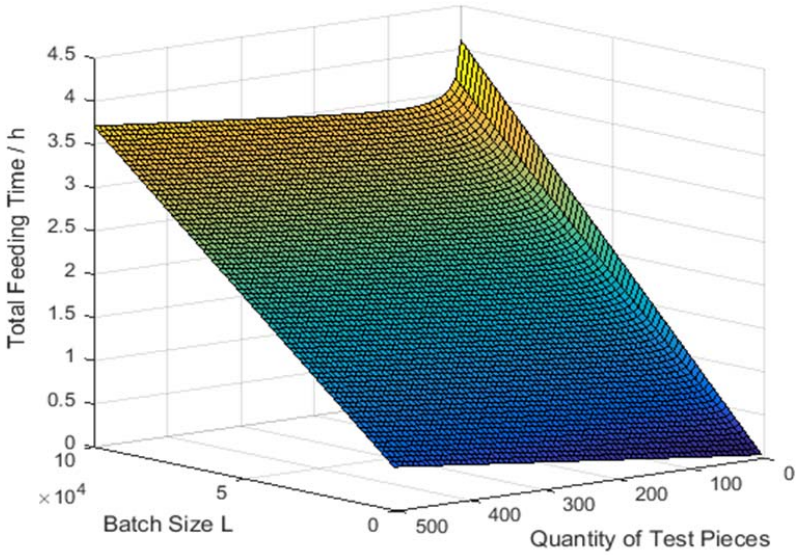


Fig. 4 Total feeding time dependent on batch size and quantity of workpieces

In Fig. 4 as well as in (8) it is shown clearly that the total feeding time steadily increases with a rising batch size *L*. In addition, in Fig. 4, it can be seen that for the case of small batch sizes the lowest total feeding time can be achieved when a small number of workpieces *j* is chosen. With an increasing batch size *L,* the total feeding time firstly decreases with an increasing workpiece quantity and adopts a minimum depending on the batch size. A further increase in the amount of workpieces results in an increase of the total feeding time. Thus, the optimal quantity of workpieces *j* increases with the batch size *L*. This behaviour can be explained by the increasing loss of time with increasing batch sizes at a reduced orientation rate. Thus, longer setting times caused by an increased number of workpieces during the initial configuration of the feeding system can be compensated by large batch sizes. To achieve a minimum of total feeding time a mathematical function that provides the optimum quantity of workpieces j_{ideal} for a respective batch size *L* is required. Thus, the locus curve of the minima needs to be found in the plane shown in Fig. 4.

The procedure for determining the locus starts by partially differentiating the plane equation (see (8)) with respect to the workpieces quantity *j*. In the following step the partial derivation is set to zero and converted to solve the equation for the amount of workpieces *j*. A subsequent approximation of the zeroing results in the locus curve, shown in Fig. 5.

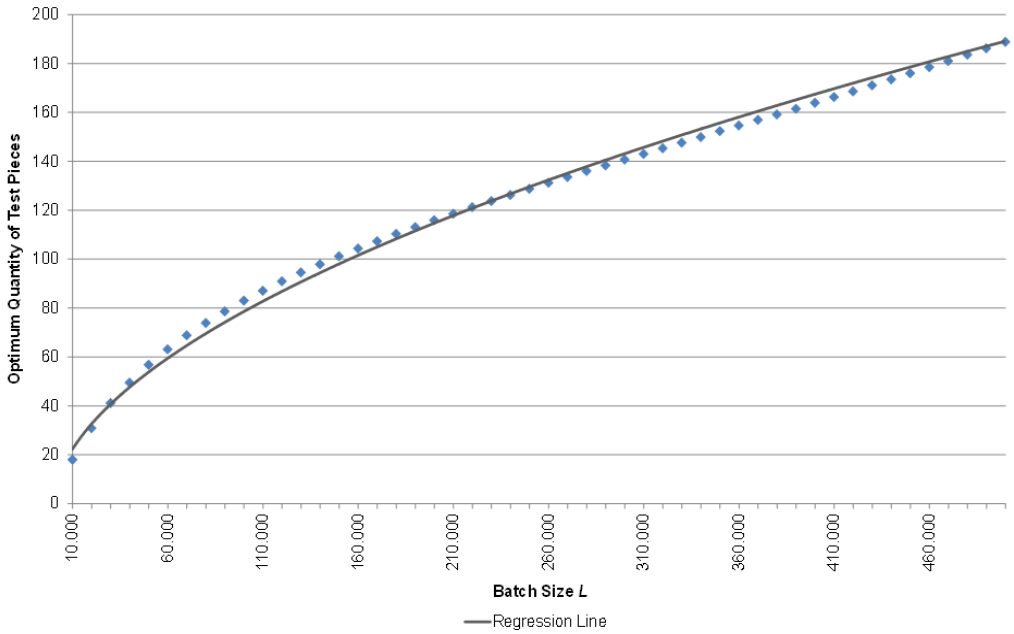


Fig. 5 Locus curve of the minimum total feeding time

The appropriate function equation is as:

$$j_{ideal} = 0.14688 * L^{0.5457} \quad (9)$$

With a given batch size this equation enables the user to choose the optimal quantity of workpieces for achieving the minimum of the total feeding time.

IV. Conclusion and Outlook

In this paper the setting time of an aerodynamic feeding system is presented regarding to its fed batch size and feeding quality. Therefore, in the first step the correlation between orientation rate and number of fed workpieces has been simulated to identify a compromise between high feeding quality and acceptable setting times. The relations between batch sizes, quantity of workpieces to be fed, setting time and the orientation rate have been formulated in mathematical equations. The final result is an equation that describes the correlation between setting time and batch size in order to identify the optimal amount of workpieces to be fed.

In further research activities these simulated results will be approved in a real-life aerodynamic feeding system of this institute.

Acknowledgement

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