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Trend-specific clustering for micro mass production of linked parts

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ABSTRACT

In micro production, small tolerances, as well as size effects increase the requirement for a fast, precise, and reliable methodology that enhances the output of assemblies. In contrast to conventional approaches, a widening of the tolerance field enables an overall improvement of the output of a process chain while assuring functionality of parts. Therefore, the consideration of trends for building sections is essential for increasing the outcome by identifying sections that can be matched. This paper presents the Linked Parts Clustering Algorithm for the identification of trend-specific clusters in linked parts and demonstrates the area of application.

1. Motivation

Optimizing processes require increasing effort, as tolerances of parts become tight. The advantage of assembling out of the box justifies the effort in many cases. If parts need to be exchanged on a single part basis, the effort is even more reasonable. Nevertheless, for some processes and parts (like injectors, turbine blades or connecting rods) the characteristics of manufacturing lead to variances in critical measures. To overcome this restriction in assembly, selected parts are matched individually.

Additionally, the effort to reach fully exchangeable products in micro manufacturing, dealing with parts of less than 1 mm in at least two dimensions, is high [1]. This is a result of both size effects [2] and small tolerances [3], which have to be taken into account. Micro parts in general will not be exchanged individually, but instead as an assembly. As micro parts are usually exchanged as assembly, after the use phase, the need for exchangeability can be neglected. If there was a method to match parts efficiently, the effort to keep the process within tight limits could be reduced.

2. Selective assembly

Various approaches for selective assembly and matching of parts are well-known from micro, meso and macro level. Kumar and Kannan [4] use genetic algorithms to obtain an optimal manufacturing tolerance for selective assembly. Asha et al. [5] use genetic algorithms to address multiple characteristics. Raj et al. [6] present an approach considering small and medium sized batches for reducing surplus parts with a non-dominated sorting genetic algorithm. Kannan et al. [7] use genetic algorithms for selective assembly and combine Taguchi's loss function for the economic aspect. Process and performance optimization using the Hungarian method for assembly of battery electrodes is introduced by Schmitt et al. [8].

Other approaches use real-time process observation. Colledani et al. [9] introduce a modelling system for the design of selective and adaptive assembly systems. Lanza et al. [10] describe an algorithm for real-time optimization while matching individual components based on their specific measurements.

The utilization of well-known variances in production for adapting tolerances has also been investigated in macro range. For large-volume products like aircrafts, Ballu et al. introduce an approach that allows a progressive modelling of features, parameters and tolerances within the design stage [11]. Anwer et al. use Skin Model Shapes for reflecting shape deviations and supporting tolerance management [12].

All of these approaches are dealing with parts, which can be handled and matched individually. For micro manufacturing, parts are combined in long sequences and are linked physically. The linkage between linked micro parts assures the retention of parts in the right order. For this reason, only approaches that consider linkages between data points are applicable. Conventional selective assembly approaches consider the data points independently of their order. For this reason, these approaches cannot be used. A methodology that does not alter the order of data points in a set sequence is required.

3. Micro mass matching

Micro manufacturing uses linkages to overcome size effects, alter handling and sorting processes for enabling mass production

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[13]. The design of the linkage is divided into ladder type, line type, and comb type [14]. Long-term storing and provision of linkages is e.g. done by winding [15]. Hence, linkages can be maintained till assembly. The product quality is assured as long as all parts in the linkage are fully exchangeable. Production processes are therefore kept in tight limits, while deviations interrupt the process. For most micro assemblies, only a few measures have to be considered in tight tolerances. Especially those measures, where assemblies are connected with each other are important. Within the assembly, measures need to be kept within a certain tolerance in combination with each other. The consideration of the tolerances for two parts moves the tolerating from part to assembly group.

Knowing the characteristic degradation curve, trends for the increasing deviation from the nominal value can be identified [16] and sequences from the linked parts can be derived. Each sequence of linked parts stays in a certain, defined value range. Identified matching sections can be provided for assembly, which individually would not be within the tolerances for exchangeable parts, but fit within the tolerance for assembly.

As trends cannot be expected to run in parallel lines for different values nor, to be steady throughout production, trends from production need to be evaluated and clustered. Thereby the trends could be taken back to design stage in order to adjust the nominal value and allow the maximum matchings from a certain combination of parts and processes [13].

From a technological point of view, matching specific clusters within the linkages need specific conveyance technique as proposed in [17], where parts are sorted and prepared in pacing frequencies of up to 400 parts per minute.

The concept of tolerance field widening and synchronisation of processes is depicted in Fig. 1, using the example of cups and spheres, that are produced as ladder type (cups) and line type (spheres). Spheres and cups are parts that could be manufactured in high rates by micro cold forming. Between these steps, a buffering is required due to different process times. In order to understand deviations and trends in the processes, in the first step every cup and sphere is measured. The critical measure is the relation of the inner diameter of the cup d_c and the diameter of the sphere d_s. To widen the allowed production array, trends need to be derived. In the second step, the tolerance field widening, these trends can be identified by clustering. Clusters will be matched afterwards by considering the fit size for maximizing the output of assemblies. Beyond that, the knowledge of the existent trends of the measured diameters $d(t)$ could be utilized. Therefore, the trends are adjusted by adding or subtracting an identified value for further improvements. This step is repeated iteratively and proven by another matching. The produced parts are stored on coils and in the third step; the parts are assembled according to the results of the tolerance field widening. The required fast and precise conveyance, as well as the output improvements by widening of the tolerance field, interdepends. To achieve high throughput rates, there should be a low number of cuts within the linked parts for minimizing interruptions while production [13]. According to the measured diameters of these parts and their deviation from the tolerance zones, e.g. due to occurring wear, preferably long sections are required. This assures a fast mass production, while widening the tolerance field. The identification of sections with similar trends facilitates long sections for assembly.

4. Cluster algorithms

Cluster algorithms are used to identify groups of data points that are homogeneous within the cluster and are heterogeneous to data points of other clusters [18]. These algorithms are often tailor-made for specific uses. Algorithms for identifying trend-specific clusters must meet the following use case specific requirement of considering linkages between micro parts.

According to graph theory, the parts could be considered as nodes and the linkages as edges between these data points. For this reason, cluster algorithms for networks must be applied. Schaeffer divides the procedure of building clusters in networks into two approaches [19]. The first one is using the edges (linkages of data points) for identifying intensively connected communities of data points as clusters. The second uses similarities of data points [19]. Within the first approach, density-based key figures are used that are non-applicable for identifying trend-specific clusters. These key figures like the density on its self are based on the interconnectedness of data points [20]. Looking at linked parts, the linkage between the data points is equal; every part has one predecessor and one successor. For this reason, only the second field of algorithms that bases on similarities is applicable. Similarities according to connectivity of data points for identification of highly connected subgraphs [21] are also not applicable. The application of distances as similarity measure is one further possibility [22]. For considering trends, the changing of the data points must be taken into account in both kinds of linked parts. While looking at the example of cups and spheres, the diameter is crucial for building functional assemblies. In Fig. 2 the order of parts is depicted exemplarily for spheres. For identifying trends, the distance between diameters of sphere i (d_{Si}) and sphere $i+1$, and therefore the distance of diameters between sphere $i+1$ and sphere $i+2$ of the linked parts is significant.

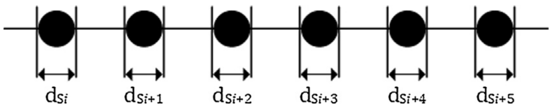

Fig. 2. Order and diameter of line linked parts as basis for clustering.

Similar distances between spheres and cups could be interpreted as similar trends. The Euclidian Distance [22] is used as a similarity key figure and ensures numerical stability. The Euclidian distance of the diameters of part i and the diameter of the part $i+1$ $\mathrm{Dist}(d_{Pi},d_{Pi+1})$ is calculated as:

$$\mathrm{Dist}(d_{Pi}, d_{Pi+1}) = |d_{Pi} - d_{Pi+1}| \quad (1)$$

Clustering algorithms can be divided in several approaches that differ in their procedural method. Hierarchical cluster algorithms are dividing or adding data to clusters corresponding depicting hierarchical structures [19]. The methodology of building clusters is more useful than dividing, since agglomerative hierarchical algorithms are starting at considering every data point as a single cluster and then building clusters until a stop criterion is reached like e.g. the number of clusters. When forming clusters by divisive hierarchical cluster algorithms, cluster fitness functions homogeneity of data or the density within clusters is considered. These approaches do not facilitate the identification of trends.

While identifying trend-specific clusters, the number of clusters and sizes of clusters should not be defined. The pre-setting of a

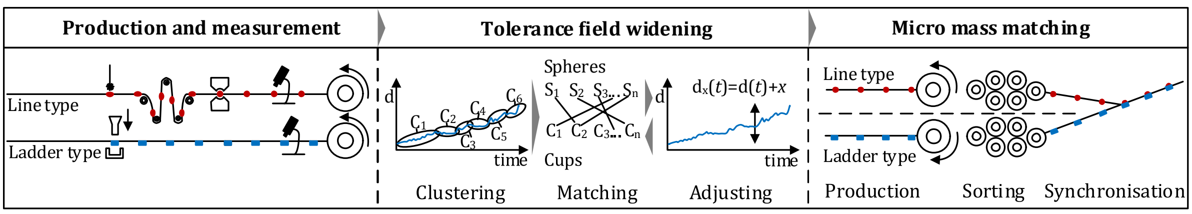

Fig. 1. Concept of mass matching of micro parts.