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Linear friction weld process monitoring of fixture cassette deformations using empirical mode decomposition

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ABSTRACT

Due to its inherent advantages, linear friction welding is a solid-state joining process of increasing importance to the aerospace, automotive, medical and power generation equipment industries. Tangential oscillations and forge stroke during the burn-off phase of the joining process introduce essential dynamic forces, which can also be detrimental to the welding process. Since burn-off is a critical phase in the manufacturing stage, process monitoring is fundamental for quality and stability control purposes. This study aims to improve workholding stability through the analysis of fixture cassette deformations. Methods and procedures for process monitoring are developed and implemented in a fail-or-pass assessment system for fixture cassette deformations during the burn-off phase. Additionally, the de-noised signals are compared to results from previous production runs. The observed deformations as a consequence of the forces acting on the fixture cassette are measured directly during the welding process. Data on the linear friction-welding machine are acquired and de-noised using empirical mode decomposition, before the burn-off phase is extracted. This approach enables a direct, objective comparison of the signal features with trends from previous successful welds. The capacity of the whole process monitoring system is validated and demonstrated through the analysis of a large number of signals obtained from welding experiments.

1. Introduction

This paper discusses the setting up of a condition monitoring system to verify the workholding stability during a linear friction welding process using empirical mode decomposition. The Introduction is split into four parts. Firstly, the background of the work is discussed in Section 1.1. After which in Section 1.2 a review is held of closely related work on condition monitoring systems found in the literature. Subsequently, some relevant developments of empirical mode decomposition for manufacturing process monitoring purposes are discussed in Section 1.3. Finally, the outline of the rest of the paper is presented in Section 1.4.

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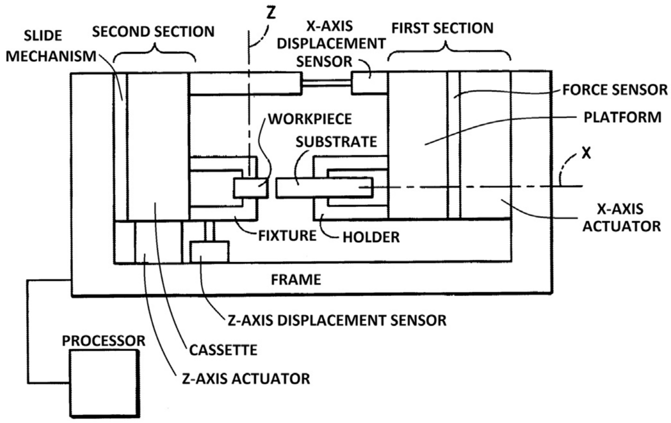

Fig. 1. Schematics of a linear friction welding machine. Adapted from Ref. [2, Fig. 1].

1.1. Background: linear friction welding

The linear friction welding process has many advantages and benefits compared with other joining processes. From a technical point of view, it has the advantage that it can be used to join two complex shaped parts. The economical benefits of the process are that the process is fast and the welding area requires little preparation. Additionally, it needs relatively low energy input and requires no consumables as means to assist the welding process, nor is there an emission of dangerous substances during the process, making it a relatively sustainable process.

However, a considerable perceived drawback of the process is that for most applications the weld quality cannot be inspected with appropriate non-destructive testing methods. Hence the weld verification is done by means of process condition monitoring in combination with statistical process monitoring, to ensure a repeatable production of reliable welds. The outcome of the linear friction welding process depends on a set of controllable input parameters and other process parameters which can be monitored for process condition monitoring purposes. The most popular application of linear friction welding is the manufacture of “blisks” (bladed disks) for aero-engines. Blisks have the advantage over traditionally designed disk assemblies that the fir tree joint is no longer needed, which leads to up to 30% weight reduction and improvements in aerodynamic efficiency [1]. The work presented in this paper focusses on the monitoring of the workholding stability during the burn-off phase.

In Refs. [2,3] the basics of the working of a linear friction welding machine for blisk manufacturing are explained. An adapted version of the working diagram that can be found in Ref. [2] is shown in Fig. 1. As can be seen in the figure, generally a LFW machine consists of a frame and two sections. The first section holds the substrate (disk) on a platform. An actuator can move this platform in a controlled manner in the forging direction x. The second section is used to provide the reciprocal oscillatory tangential motion required for the LFW process. It comprises of an actuator that provides the motion to drive the cassette in the tangential direction z. The machine's tooling consists of the inner cage wherein a cassette is placed that holds the workpiece (blade) [4]. To ensure workholding stability in the y-direction, the cassette deformation during the process should be kept below certain limits.

During the LFW process the workpiece and substrate are datumed and brought in contact with each other up to a certain contact pressure. This is also known as the contact phase [3] and is depicted in Fig. 2. The workpiece in Fig. 1 is moved in a linear, reciprocating way, tangential and relative to the other part. The friction generates heat, which is enough to make the material ductile. In the first instance the rubbing is used to remove the outer layer of material, this is called burn-off in this work and comprises what is generally known as the initial (conditioning [3]), the transition and equilibrium (frictional [3]) and the first part of the deceleration (forge [3]) phases [5], see Fig. 2. In the ramp-down phase, which is the first stage of the deceleration phase in Ref. [5] the amplitude of the tangential reciprocating motion is decreased, as can be seen in Fig. 2. After this, when the reciprocating movement is completely stopped, and the moving part is placed in the desired position, the part and substrate are then forged onto each other in the second part of the forge or deceleration phase. It should be noted that in the work presented here, the welding process is monitored for the duration of the tangential motion. These oscillations take place from the initial phase to the ramp-down phase, as shown in Fig. 2 and this period is denoted as ‘period of interest’ in the figure. Furthermore, it should be noted that this work studies the reproducibility of the welds, hence, the analysis of the influence of the different phases on the weld is not a part of this study. The interested reader is referred to the papers by Vairis and Frost [5] and Bhamji et al. [3], where the influence of the weld phases on the parameters is discussed in much greater detail. However, the methodology presented here can be easily extended to do such a mechanistic analysis of the weld parameters.

A LFW machine is typically equipped with several sensors that can be used to monitor the process variables, some of these sensors are shown in Fig. 1. The processor is used to control the processes and capture the data from the sensory system. On the linear friction welding machine used for the experiments presented in this work, force sensors are placed on the cassette by the