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On-line manipulator tool condition monitoring based on vibration analysis

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ABSTRACT

This article presents a method of processing and analyzing the measurement signals used in the problem of diagnosing the state of a manipulator's tool. The analysis of the signals was performed within the domain of time and frequency. The signals utilized in the analysis were the mechanical vibrations and the rotation speed of the tool. The database for analysis was obtained in a research environment and it includes the instances of the functioning of the system with tool in good technical state as well as instances with a damaged tool. With the intent at reducing the data, the registered signals are represented with the use of selected features. The preliminary selection of the significant features of the signals is made with the use of the sequential feature selection procedure. The reduced set of features is used for the creation of a tool condition classifier, which has a form of an artificial neural network. The obtained classifier operates on-line on robotized system and generates diagnostic information on the state of the tool.

1. Introduction

The issue presented in this article has its origins in the robotization of the machining processes of aircraft engine components. Proper implementation of robotized machining processes demands the stability of a substantial amount of the parameters affecting the process and the quality of the manufactured product. Of particular importance is the ability of maintaining high quality of the tool applied during processing, as well as an appropriately early and automatic diagnosis of the tool damage appearing. This is an especially important aspect mandated by economic reasons, because damage of the tool results in a reduction in the quality of manufacturing as well as damage to the components of the aircraft engine which bring with them heavy financial losses.

Grinding of selected surfaces is one of the final stages of processing aircraft engine components [1]. Due to the nature of aircraft engine component production, often arises the problem of uncertainty of the surface location, which requires processing. This is due to the manufacturing technology of casting which is associated with what is referred to as contraction and with considerable deviation of dimensions and cast shape in comparison to the designed element. This has profound implications on the robotic machining processes of such components [2]. A need for complex robotized systems arises in which appropriate assortment of tools plays a significant role. The tool itself needs to be characterized with a high

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flexibility so that in conditions of high uncertainty of the position of the workpiece's surface the tool-to-surface contact was as gentle as possible. This requirement can be fulfilled by applying such tools as brushes with ceramic fibers. However, such tools are delicate, wear out quickly and often end up being damaged. Due to the high rotational speeds (up to 6000 rpm) used when machining with such tools, they must be carefully balanced and any damage is simply unacceptable. Typical damages of such a tool is the breaking of its fibers. Such damage adversely influences the precision of machining and the surface roughness for two reasons. The first is the reduction of the contact surface of the tool and the work surface, and the second is the occurring imbalance which leads to the appearance of mechanical vibrations.

The paper presents a methodology of creating a tool state classifier that, based on the available measurement data, will assign the current state of the tool to one of the two defined classes. The phenomenon of vibrations and parameters of the vibratory motion of the unbalanced tool have been used as a carrier of information about the tool condition [3]. This article falls within current research trends for tool condition monitoring [4–10].

This paper presents a solution to the problem of diagnosing the state of the IRB 140 industrial manipulator's tool, which is used in grinding processes of aircraft engine components. The article continues and expands the topics presented in the publication of authors [11]. Compared to the mentioned article, in this paper a different method of selection of relevant signal features for condition monitoring is used. Instead of analyzing decision trees, a sequential feature selection procedure is applied. Moreover, the current publication presents detailed aspects concerning the implementation of the developed method on stand of an industrial nature. Section 2 presents the testing environment and the method of performing measurement experiments with the aim to build a database. Section 3 presents the method of analysis of the measurement data expressed in the domain of time and frequency. Section 4 has been devoted to the issue of classifying the state of the tool based on the obtained database, while Section 5 describes the implementation of a monitoring system for the state of the tool in a robotized environment. The obtained results are summarized and commented on in Section 6.

2. The laboratory researches

This section presents a description of the laboratory stand used during testing and the method of conducting the measuring experiment. The main element of the laboratory stand is the industrial manipulator IRB 140 shown in Fig. 1.

The robot is intended for the realization of research work in the field of robotization of the machining processes using position-force control methods. In addition to standard equipment, the robot is equipped with a Delta SI-330–30 force and moment sensor (made by ATI Industrial Automation) placed at the end-effector. Moreover, it is equipped with a 400 W power ADEV42 electric spindle (made by Precision Drive Systems), which rotational speed is in the range from 6000 to 24,000 rpm. This is a drive intended for light to medium duty applications such as precision machining. The drive is controlled by an OMRON MX2 inverter. The cutting tool, which in this study is a ceramic fiber brush (A21-CB15M made by Xebec), is mounted in the holder of the drive.

Fig. 2 represents the brush tool with ceramic fibers in a standard protective sleeve made of plastic. Fig. 2a presents a new and unused tool, while, Fig. 2b presents a typically damaged tool due to collisions with the machined element. The ceramic

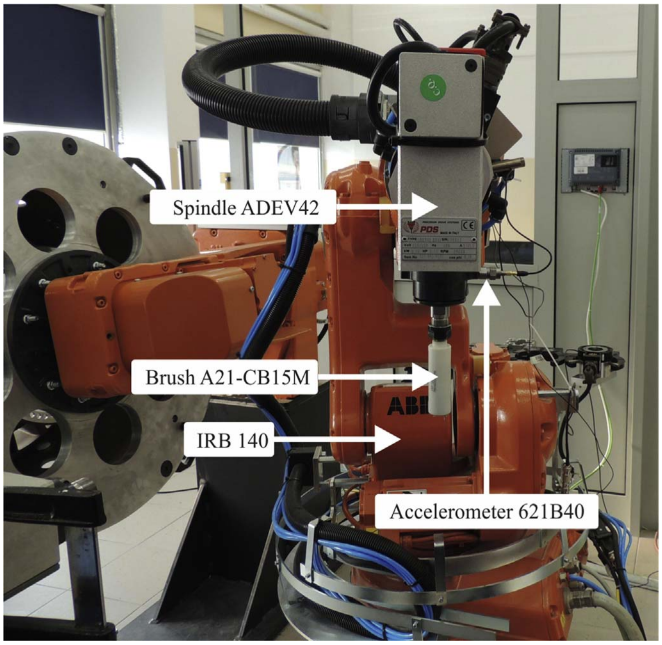

Fig. 1. IRB 140 industrial robotic manipulator with equipment.

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