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State-based and self-adapting algorithm for condition monitoring

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Abstract

Condition Monitoring and Maintenance prediction are permanent demands of state-of-the-art machine tools. Their IT-infrastructure including drive control systems and specific sensors deliver extensive amounts of data for monitoring. However to combine and link this data to define critical characteristic values remains challenging. The paper presents a novel approach to deal with these tasks. Firstly equal machine states are detected at different times by checking and comparing several parameters. If an equal state is detected an algorithm is executed which leads to a characteristic value. The value as well as its limits is self-adapting and time-depending by constant redefining based on the machine history.

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Keywords: Condition monitoring; Algorithm; Maintenance; Self-adapting; Characteristic value; Machine state

1. Introduction

Condition Monitoring and Maintenance prediction are permanent demands of state-of-the-art machine tools [1], [2] [3]. Their IT-infrastructure including drive control systems and specific sensors deliver extensive amounts of data for monitoring. By default the data is gathered by the control. These signals are primary for process control purposes like NC-machining but could as well be used as measuring signals for condition monitoring [1], [4] - [9] There is a broad range of options to correlate this times-depending data with the state of the overall system and his subcomponents [1], [4] - [9].

The basic task in condition monitoring is to combine the vast amount of information available and link it to the current state of components. However to derive concrete characteristic values and divide these values in usable categories like “normal”, “critical” or “worn out” remains challenging. The prediction of the remaining life span of components is even more complicated. Furthermore the definition of static or even deterministic defined characteristic values with strict limits is inappropriate for heavy and special purpose machine tools with constantly changing workpieces and the inclusion of multi-process operations like drilling-milling or boring-milling. To avoid arbitrary alarms the characteristic values and limits have to be defined very broad which detracts most of their benefit.

The main problems can be traced back to two fundamental challenges:

- Changing machine configuration and environment in general including changing process, changing workpiece, changing temperatures and changing dynamics and distribution of components (drives)
- Time-depending drift processes like running-in characteristic of components and normal noncritical wear of components

To address these main tasks and receive stable and usable characteristic values a two-stepped approach is described in the following:

- (1) Detection of equal states (chapter 2)
- (2) Based on (1) deriving of dynamic and self-adaptive characteristic values (chapter 3)

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2. Detection of equal system states

The general approach to take changing boundary conditions into account consists of the detections of equal states at different times. This means that the machine tool performs the same process at two different points in time, has an equal or very close configuration including feed-drive positions, workpiece and auxiliary systems. Furthermore even the environmental conditions including temperature should be comparable to some degree.

2.1. Definition of different machine states through trigger

At first step a set of interesting states has to be defined which can be usable linked to the correct functionality and/or wear of a component. An example could be the tool-changing function of a machining center and the related operations.

If a state is qualitatively described all parameters which define this state have to considered, this includes:

- Operational mode (automatic, manual)
- Technology (boring, milling, turning)
- Tool (type, size, defined by an tool ID)
- Workpiece (size, material)
- Feed-drive configuration (position)
- Workpiece (size, material)
- Feed-drive dynamics (speed, acceleration, jerk)
- Motor-load and/or feed-specific force/moment
- Current component temperature as indicator for preloading of bearings and structures
- Environment: current temperature and humidity
- Coolant-flow (can have feedback to process forces and temperatures)

There exists a wide range of possible triggers and the definition of “equal” states is always depended on the concrete monitoring task/component.

Fig.1 shows the principal approach to detect two different states at two different points in time.

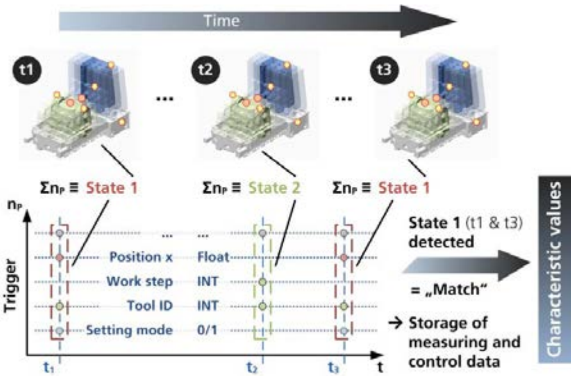

Fig. 1. Detection of equal states

2.2. Trigger characterization and IT-implementation

Triggers can further be categorized regarding their IT characteristics and how the time-related values chance. One approach is a 3-level categorization:

- Must-trigger; have to be always fulfilled, e.g. operational mode: automatic
- Static trigger; typical integer values, e.g. tool ID, operational step
- Dynamic trigger; typical floating values, e.g. position of a feed-drive axis, temperature of a component

Table 1 gives an example for the principal IT-definition of a trigger. The combination of several triggers – linked to specific values – defines a machine state as shown in fig. 1

Table 1. Example for trigger definition

	IP-address of control	(there may be several controls)		
	Software version	(software version in which the data is available)		
	Cycle time	(in which cycle time is the data available and must be considered)		
ID	Description	Address	Format	Value-range
1	Machine in production	DB110.DBX1.0	Bit	false/true
2	Machine in set-up	DB110.DBX1.1	Bit	false/true
3	Tool ID	DB111.DBW4	INT	1-32000
4	Work step	DB111.DBW6	INT	1-32000
5	Rotary speed	DB111.DBW12	Float	-5000 ---- +5000
…	…	…	…	…

Some of the triggers, especially dynamic ones, can be triggers to detect a machine state as well as a measuring / characteristic value (or a base for them). For example a state can be defined – amongst others – by an x feed-drive speed of 0.5 m/s +/- 0.05 m/s. So these (floating) value acts as a trigger. Regarding the deduction of characteristic values the very same value can be used to detect changes of the fluctuation of the x-feed drive speed over time (see fig. 2). In this case the x feed-drive speed acts as a trigger, while the derived feed-drive fluctuation for different times (same state) acts as a characteristic value.

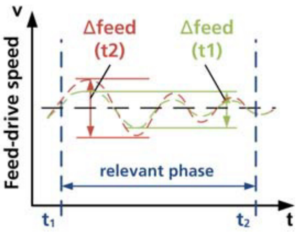

Fig. 2. Feed-drive speed as trigger and characteristic value