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# Real Time Prediction of Flank Wear by Neuro Fuzzy Technique in Turning

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**Abstract**

Machine tool automation requires reliable online tool wear monitoring techniques for automated manufacturing. Automatic detection of the state of tool wear in metal cutting operations is an important industrial problem. In this paper, an ultrasonic system is presented to monitor the tool wear in turning. The ultrasonic waves reflected from the wear region were analysed and correlated with flank wear. The reflected ultrasonic signal is analysed in both time and frequency domain. Artificial intelligence techniques such as artificial neural networks, fuzzy logic and the neuro-fuzzy technique have proved their potential in monitoring the manufacturing processes. Here, Adaptive Neuro Fuzzy Inference System (ANFIS) is used to identify the tool wear. The experimental validation runs show the system can predict the tool wear with average error of 2.5%. The decision making algorithm (DMA) is presented to determine the status of wear.



Keywords: Turning, Condition Monitoring, HSS tool, Neuro Fuzzy system, Machining, Tool wear .

## 1. Introduction

In machining process, a tool has a fixed life time in accordance with tool manufacturer recommendations or past experiences. This tool change policy has two drawbacks, at one end; a worn tool without being exchanged in time will produce out of specification parts or even cause catastrophic tool breakage, and at the other tools being thrown away prematurely over time will incur a huge waste of manufacturing resource.

Several monitoring methods have been developed during the last few decades by many researchers. These methods may be classified in two groups, direct and indirect methods [1]. Direct methods are based upon direct measurements of the worn area of the tool using optical sensors [2], vision systems [3, 4] etc. These methods have the advantage of high measurement accuracy, but cannot be easily adopted for on-line applications.

Various indirect methods have also been developed in which the state of the wear is estimated from measurable parameters such as cutting forces [5], vibration [6], acoustic emission [7, 8], cutting temperature and surface roughness. However few reliable indirect methods are established for industrial use. This is mainly due to complexity of machining process and the uncertainty in the correlation between the process parameters and tool wear.

The vision based methods have the advantage of high measuring accuracy, but cannot be easily adopted for online applications because of the interruption of coolant and chips. The identification of tool wear by multi-sensory approach was proposed by many researchers. U.Natarajan et al [9] presented a remarkable work in tool wear monitoring, which uses force, temperature, power signals to quantify the status of the tool wear. Though the multi-sensory approach produces good results, the cost associated with this method have somewhat discouraged its use among researchers.

An ultrasound on-line measurement of gradual wear of the flank during the turning operation was developed by Taysir H Nayfeh [10]. The method relies on inducing ultrasound waves in the tool, which propagates the length of the tool and are reflected by nose and flank surfaces. The amount of reflected energy is correlated with tool wear. The analytical model for tool wear through ultrasonic technique was presented by Nidal H et al [11, 12]. In this work, the change in tool geometry due to gradual wear has been related in a mathematical form, to the change in the acoustic behaviour of the ultrasonic waves inside the body of the cutting tool. Physical laws governing the propagation and reflection of ultrasonic waves along with geometrical analysis of wear area were used in deriving the mathematical model. Wavelet analysis for tool chatter monitoring was presented by the same

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authors, provides different approach in tool wear monitoring [13].

The ultrasonic technique is neither a direct nor an indirect methodology, which combines advantages of both the methods. The ultrasound waves reach both the nose and the flank region of the tool directly and provide information of the nature of the wear through the reflected echoes. Since it is not a secondary signal from the machining, it is affected by the machining parameters to a smaller extent.

In the presented work, the various ultrasonic signal parameters; amplitude, root mean square (RMS) of the signal, pulse width, peak frequency shift and dB loss are used to define the height of the tool wear. The spectral analysis of the ultrasonic signal provides a different approach for tool wear monitoring. The analysis is carried out by a High Speed Steel (H.S.S) tool where the advantage of H.S.S compared with carbide tool and other cutting tools is higher toughness and lower price. This allows the economical and ecological application in the field of lower speed and feed combined with instable cutting conditions.

System modelling based on conventional mathematical tools is not well suited for dealing with ill-defined and uncertain systems [14]. By contrast; a fuzzy inference system employing fuzzy if-then rules can model the qualitative aspects of human knowledge and reasoning processes without employing precise quantitative analysis. Since the tool wear formation is a nonhomogenous continuous process, the analytical and statistical models may not be suitable for online measurement and control [15]. Here ANFIS is used as a modelling algorithm which relates the ultrasonic parameters with tool wear and presented for online prediction.

## 2. Experimental Details

The flank wear is measured conventionally by a tool maker's microscope of 10 microns accuracy. The flank wear is generally measured from the original cutting edge. The flank height is measured in each stage and the maximum height of flank is considered for experiments. In these stages, the corresponding ultrasonic measurements are also taken. The probe is placed in the backside of the tool to approach the flank wear as shown in Figure 1. The transducer used is a panametrics (V-112-rm) round shaped, operating at a frequency of 10 MHz. Heavy duty soluble oil is pumped through the tool holder to serve as the coupling medium of the transducer to the tool. In addition, slow circulation of the fluid cools the transducer during cutting. The limitation of ultrasound technique is the coupling medium required to induce the ultrasonic waves in the workpiece for flaw measurements. But online measurement uses the coupling medium as coolant.

The HSS tool of 15 mm thick, 100 mm long, side clearance angle of 2 degrees, side cutting edge angle of 3 degrees and with rake angle of zero degree is chosen for accelerated wear testing. In this case, initially for a fresh tool, the received signals are the resulting signal of multiple reflections of ultrasonic waves inside the complex tool geometry.

In the ideal case, the increase in the reflected energy obeys the square law. But in turning, the principles does not strictly hold since the reflecting surfaces are marred and are at off angles from the normal to the transducer, thus resulting in complex wave interactions. Gradual tool wear manifests in two locations, which are the primary and secondary flanks. The present tool-transducer configuration can detect the first waveform. The second form, crater, can only be detected when it is very severe.

No effort was made to isolate the nose from flank wear, since they are directly related to each other. In addition, isolating the individual wear contributions to the individual ultrasonic echoes is not possible. Gradual wear of the nose and flanks is a comparatively slow process, of the order of minute or perhaps hours in some cases. Several tool wear tests were conducted to evaluate gradual wear measurements of the nose and the flanks. The work material used is EN 29 hardened steel with 60mm diameter and cutting parameters are speed range of 600 rpm, feed of 60 mm/min with 0.5mm depth of cut.

## 3. Results and discussion

The wave strikes on the flank face, is internally reflected to the top surface or rake face, which is then reflected back, along a different path to the transducer. In the course of cutting, due to wear, flat spots begin to develop at the tool nose and the flank, this change in the geometry of the tool serves to change the total amount of reflected ultrasonic energy.

It is noted that the amplitude of the flank signal increases with the wear land height, since ultrasonic is more sensitive when it hits the flat spots (Figure 2). Due to the same reason the pulse width also increases with wear land height (Figure 3). It is observed that the increase in wear land height increases cumulative pulse width of received signals. This is because an increase in wear land height provides the plane which has lesser inclination compared with end relief angle.

The RMS values for the reflected ultrasonic signals are calculated. From the Figure 4, it is seen that flank wear has a definite trend with RMS values of the ultrasonic signals. In all cases the wear varied randomly at different measurements points, from uniform to somewhat irregular. Tool is tested beyond the standard tool life to verify the behaviour of the correlation.

From the power spectrum, the average power received by the transducer increases with wear. Therefore the dB loss decreases with increase in flank wear height (Table 1). It is also found that the frequency components shift towards the higher frequency as the wear increases. Initially the ultrasonic waves for reference tool have the low frequency components because of multiple internal reflections. It attenuates the high frequency components the wear on the flank promotes the direct reflection of signal and it is received by the ultrasonic probe.

### *3.1. Tool wear prediction with ANFIS*

ANFIS on-line identification of tool wear starts by obtaining the data set (input-output data pairs) and dividing it into training and validating data sets. The training data set is used to find the initial premise parameters for the fuzzy membership functions by equally spacing each membership function. The values of the premise parameters are fixed, so the overall on-line

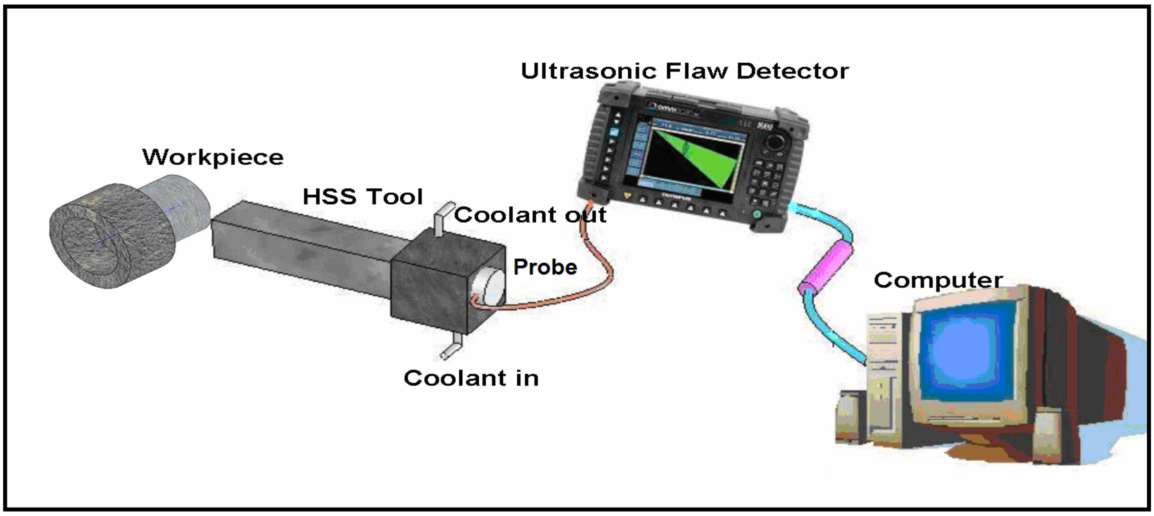


Figure 1 Online setup for flank wear monitoring

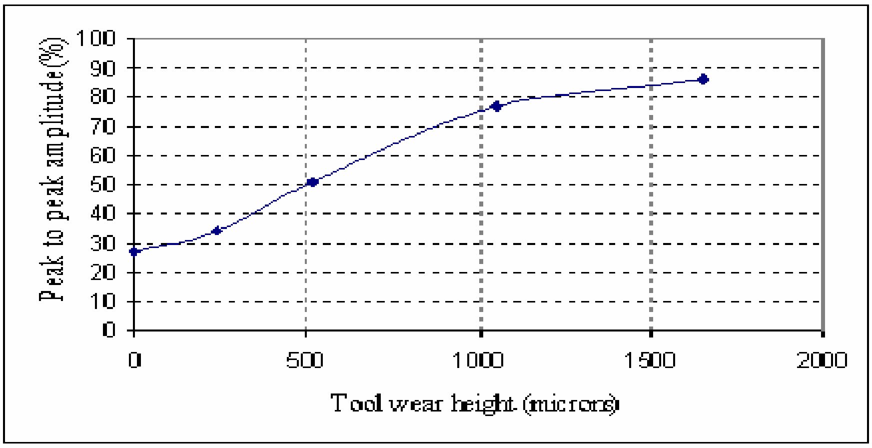


Figure 2 Wear land height Vs Peak to peak amplitude

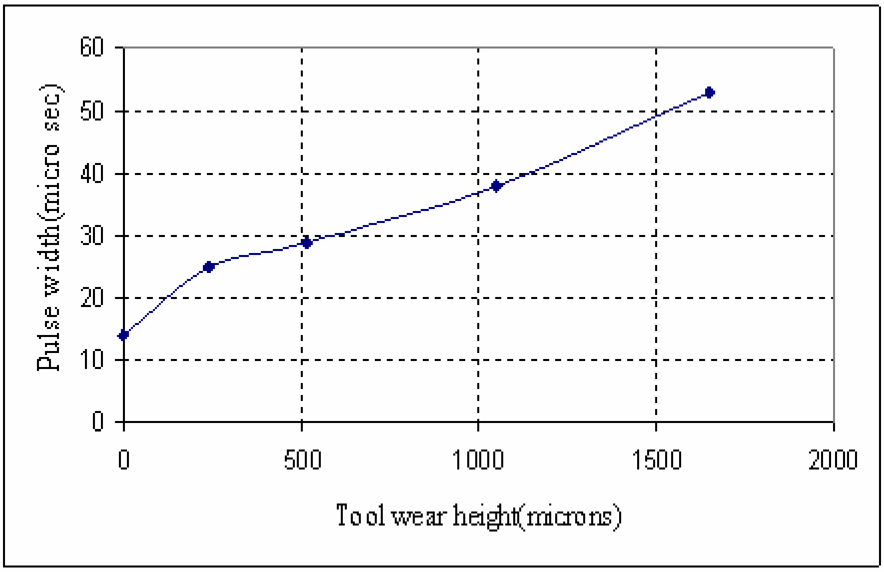


Figure 3 wear land height Vs Pulse width

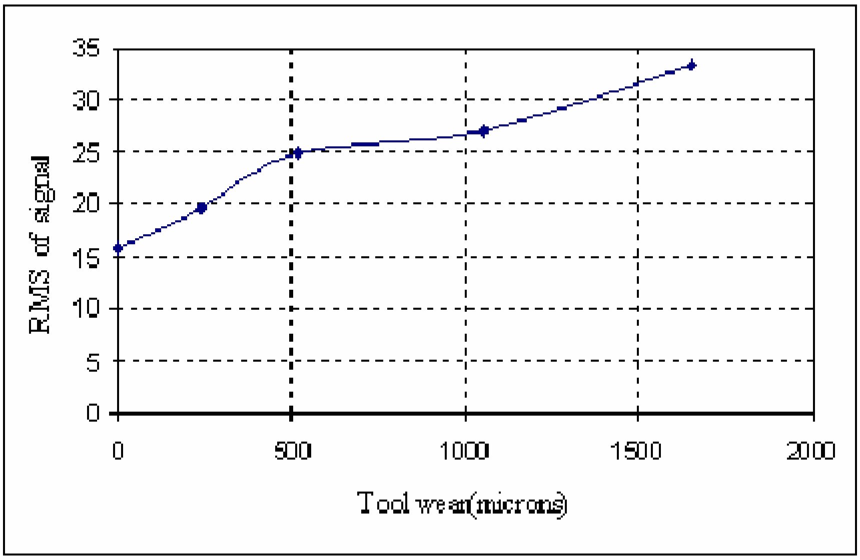


Figure 4 Wear land height Vs RMS value of signal

Table 1 Tool wear Vs Spectral parameters

| Tool Wear(microns) | dB loss | Peak Frequency Shift(MHz) |
|---|---|---|
| 0.00000 | 0 | 1.70 |
| 242.00000 | -4.06 | 2.60 |
| 517.00000 | -10.47 | 3.10 |
| 1052.00000 | -17.53 | 4.30 |
| 1652.00000 | -19.181 | 4.70 |

predicted tool wear, can be expressed as a linear combination of consequent parameters.

*3.1.1. ANFIS Parameters*

Inputs for ANFIS: ANFIS takes the experimental data of the ultrasonic parameters in time domain and frequency domain as input training data of the system. In time domain the peak amplitude, RMS of received signal and pulse width are taken as inputs for ANFIS system. In frequency domain the peak frequency shift, average power of the signal is taken as input.

Architecture of ANFIS: A total of 41 network nodes and 5 fuzzy rules are used to build the ANFIS Architecture as shown in Figure 5.

Membership Function: Bell-shaped membership functions were used to train ANFIS because it achieved the lowest training error of 0.139 at 100 epochs, as shown in the training curve of Figure 6 and error training curve of Figure 7.

The fuzzy logic toolbox of MATLAB 7.1 was used to train the ANFIS. Different ANFIS parameters were tested as training parameters in order to achieve the perfect training and the maximum prediction accuracy.

## 4. Validation of model

The on-line tool wear prediction system was validated by randomly selecting five independent experimental validating data points which are different from other five points used for ANFIS training, shown in Figure 8. For validation, the amplitude, RMS, Pulse width and spectrum parameters are considered as in training. The set of data points comprise the time and frequency domain parameters are given as an input for FIS validation. The validation results show that the ultrasonic system is capable of monitoring the tool wear with minimal average error of 2.5%

## 5. Decision making algorithm for tool wear monitoring

The overall purpose of the method is to track progressive tool wear so that catastrophic tool failure can be avoided by taking necessary corrective actions, such as stopping the feed and spindle rotation, in sufficient time. In order to determine the wear status of the cutting tool (sharp, worn but still workable and dull) during any turning operation correctly, a decision making algorithm (DMA) is proposed in this work (Figure 9).

Generally, an average flank wear height of 900 microns is considered as worn tool. But the tool changing is mainly based on the finish required. The ultrasonic parameters are

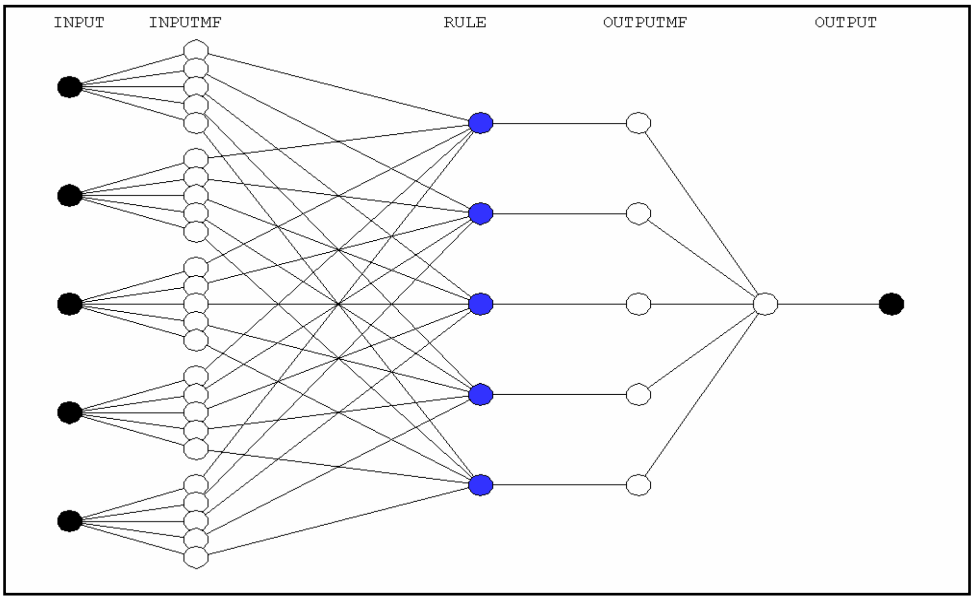


Figure 5 ANFIS Architecture

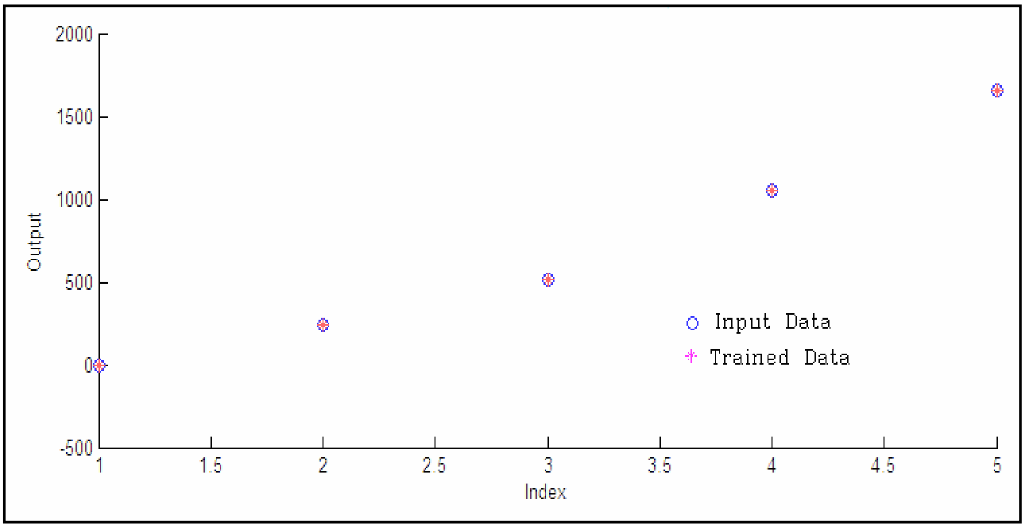


Figure 6 ANFIS training

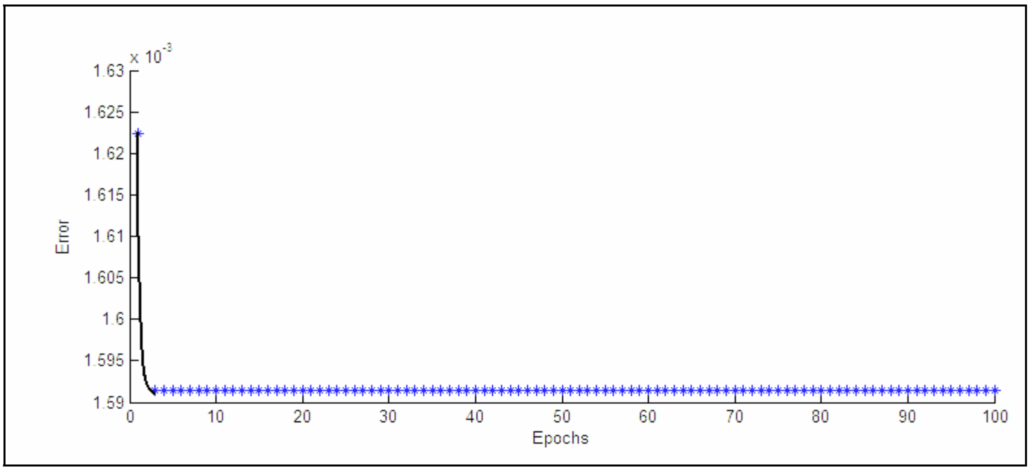


Fig 7 ANFIS training error curve

 

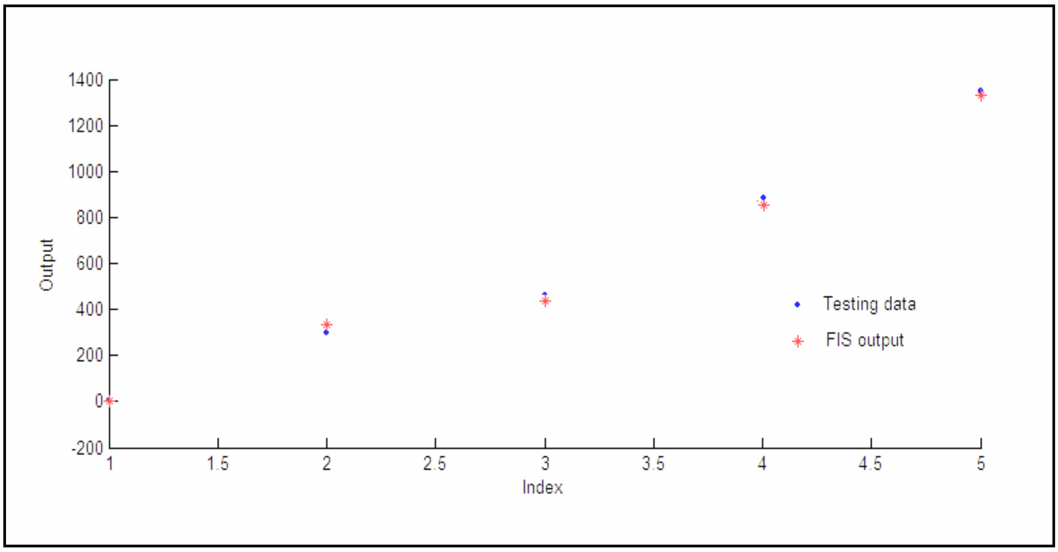


Figure 8 ANFIS Validation diagram

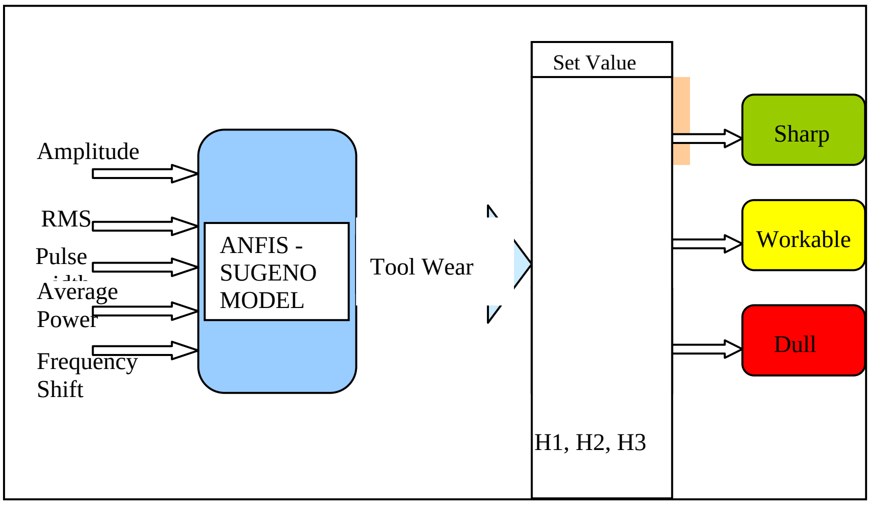


Figure 9 Decision making algorithm for tool wear.

given as input for FIS which gives the flank height. The value of predicted wear will be the input for the decision making algorithm written in C language and interfaced with monitoring system, where the decisions are represented by H1, H2, H3 respectively and have the values as sharp (up to 375 microns), workable (between 375 to 870 microns) and dull stage (above 870 microns).

## 6. Conclusion

In this work a new approach for tool wear monitoring was introduced by using ANFIS. The basic inferences shows that the amplitude level of ultrasonic signal, RMS of received ultrasonic signal, pulse width duration in TOF mode during cutting process is affected by the tool wear. The frequency domain of signal shows the distribution of frequency components and frequency shift in the received signal which can be related to flank wear.

Correlation between the ultrasonic parameters and flank wear shows that every parameter is contributing in definition of flank wear growth. ANFIS was developed, which considers the ultrasonic parameters in time and frequency domain. The statistical methods may not be suitable for non linear systems, and for online application. The ANFIS solves the stated problems. The error is minimized upto 2.5%. Thus the system can be used in online monitoring of flank wear in a single point cutting tool. The decision making algorithm presented in this work determines the tool wear status in real time.

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