Failure Analysis of Machine Tools using GTMA and MADM method

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Abstract

Machine tools play a vital role in the performance of manufacturing industries. Machine tools form a complex system consisting of various sub systems and components. Failure of machine tools can take place if any of the components of the sub systems fail to perform its function. Machine tool includes various complicated systems such as electrical systems, hydraulic systems, electronic systems, bearings, gears, belts and lubrication systems. These machine tools are subjected to different kinds of failure problems in operation. This work is based on the study of such failures to identify the critical sub systems of these machine tools. The failure analysis of machine tools was carried out using graph theory-matrix approach (GTMA) and multiple attribute decision making (MADM) method. The failure data of machine tools was collected from industries and analysed to determine the critical component or sub system.
Keywords – Critical sub system, SAW Method, WPM Method, MTFCI.

1. Introduction

The investigation of critical sub system of machine tools is based on the application of graph theory- matrix approach and multiple attribute decision making approach. To represent the failure cause of machine tool sub systems and components a Machine tool failure causality diagraph is used. The machine tool failure causality diagraph represents the graphical relationship between the failure contributing events, then a machine tool failure causality index (MTFCI) is calculated which shows the critical system of machine tool [1]. In multiple attribute decision making approach SAW and WPM method is used to calculate the failure index. These data will be useful to the producer of machine tools for finding the fault creating components or sub systems. Based on the failure data the condition monitoring system can focus on the critical component for their proper working [2]. The failure data of various machine tools like Lathe, Drilling, and Press brake machines have been collected from KKE Wash system Pvt Ltd and Onkar Furnitech MIDC Hingna Nagpur India, for present investigation.

2. Methodology of GTMA and MADM approach

2.1 The methodology for the application of graph theory- matrix approach (GTMA) is given below –

(a) The failure causes and their modes were identified and severity was assigned to each.

(b) Machine tool causality diagraph and matrix was developed.

(c) The values of severity and causality relation were substituted in the above matrix.

(d) The value of machine tool failure causality index (MTFCI) by matrix method was obtained using MATLAB programming.

In this project four of the most important contributing events or failure modes are selected and it is given below –

(1) Component damage
(2) Fuse burnt
(3) Circuit fault
(4) Looseness

A diagraph of all four failure modes is given below in which each node represents a failure mode and the arrow indicate relation among various nodes -

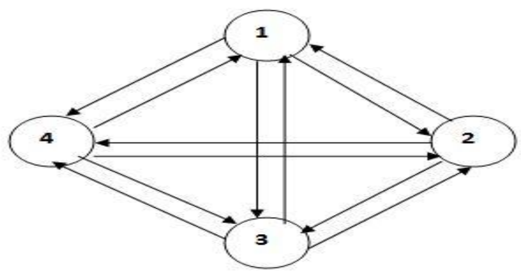

Fig 1- Diagraph showing the failure modes

If there are a large number of contributing events then there will be large number of nodes and above diagraph will become complex. So to handle the machine tool failure causality diagraph conveniently using a computer, the matrix approach is adapted [3].

If there are M numbers of failure contributing events for a failure cause and the causality relations exist among all the failure contributing events and there are no self loops then the machine tool failure causality matrix B is written as –

$$
\begin{array}{cc|ccccccc|}
 & \text{Event} & 1 & 2 & 3 & \ldots & \ldots & M \\
 & 1 & s_1 & c_{12} & c_{13} & \ldots & \ldots & c_{1m} \\
 & 2 & c_{21} & s_2 & c_{23} & \ldots & \ldots & c_{2m} \\
\mathbf{B} = & 3 & c_{31} & c_{32} & s_3 & \ldots & \ldots & c_{3m} \\
 & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
 & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
 & M & c_{m1} & c_{m2} & c_{m3} & \ldots & \ldots & s_m
\end{array}
$$

2.2 The methodology for the application of multiple attribute decision making (MADM) approach is given below-

It refers to making decisions in the presence of multiple usually conflicting criteria. Multiple attribute decision making is an approach used to solve problem which involves the selection from among a finite number of alternatives. It consists of two methods –

(a) Simple additive method (SAW) – It is also called weighted sum method and it is widest used MADM method. The each attribute is given a weight and the sum of all weights must be 1. Each alternative is assessed weights for regard to every attribute to reflect relative importance. The permanent function P_i is given by

$$P_i = \sum_{j=1}^{M} w_j \, (m_{ij})_{normal} \qquad \text{..........(1)}$$

(b) Weighted product method (WPM) – In this method each normalised value of an alternative with respect to an attribute i.e. $(m_{ij})_{normal}$ is raised to the power of relative weight of the corresponding attribute. The alternative with the highest P_i is considered the best alternative [4].

$$P_i = \prod_{j=1}^{M} [(m_{ij})_{normal}]^{wj} \qquad \text{.........(2)}$$

Where, $(m_{ij})_{normal}$ = normalised value of an alternative with respect to an attribute.

W_j = weights assigned to different events.

3. Failure data collection and analysis

Failure analysis is concerned with collecting and analysing the data in order to find out the reason for failure. When failure occurs the machine tool ceases to perform its specified function. Failure data were collected from KKE Wash system and Onkar Furnitech MIDC Hingna Nagpur, over a period of five years on several conventional machine tools such as lathe, drilling and press brake machines. It contained the following information – Product code, machine number, batch number, date of repair, failure code, failure effect, repair time, down time, repair process, number of break down, size of machine tool, causes of failure and date of failure[5].

All failures have been grouped into four failure modes which is responsible for the failure of machine tools –

(1) Component damage (CD)
(2) Fuse burnt (FB)
(3) Circuit fault (CF)
(4) Looseness (LS)

3.1 Calculation of indices of lathe machine

Lathe has been classified into various sub systems as shown in Fig 2. The sub systems of lathe machine are Head stock (HS), Tail stock (TS), Carriage (C), Feed mechanism (FM), Electrical system (ES), Hydraulic system (HS) and Coolant system (CS). The failure data has been collected from KKE Wash system Pvt Ltd, Nagpur. The failure frequency and down time have been taken into consideration for deciding critical sub system of lathe machine in this investigation.

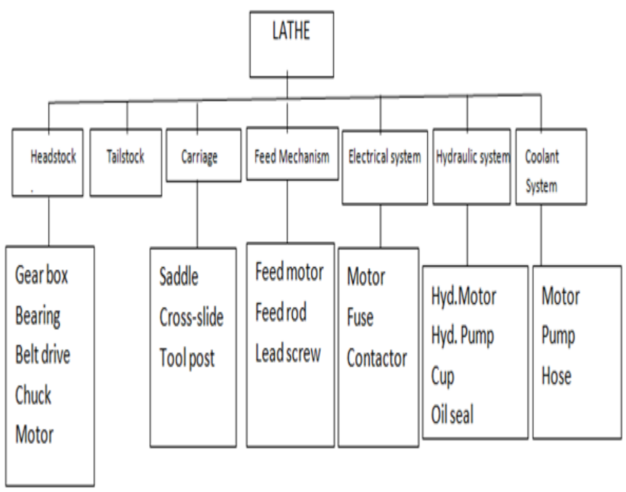

Fig 2 – Classification of lathe sub systems

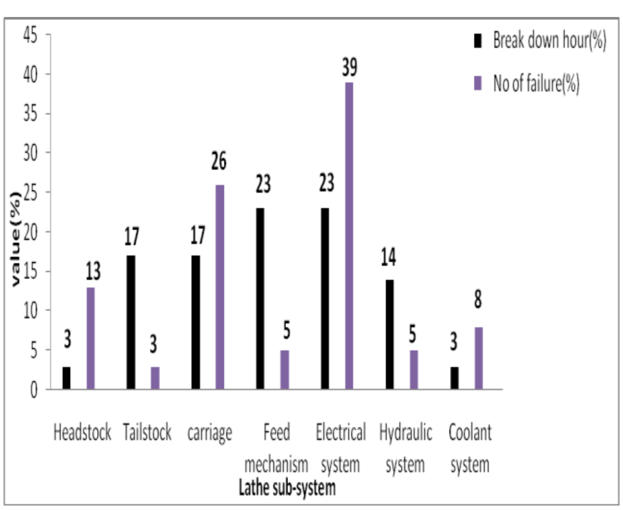

Fig 3 – Failure frequency and down time of lathe machine sub system

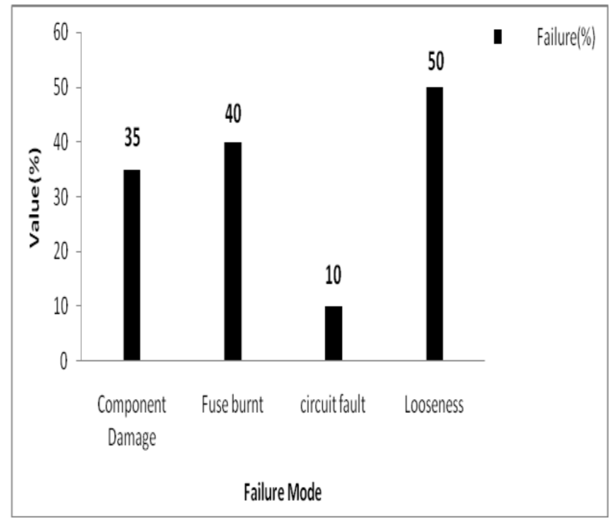

Fig 4 – Histogram showing the different failure Modes of lathe machine

The failure data received from industry is shown in Fig 3 & 4, the severity judgement values in normalised form are assigned to the failure causes and these values are given in the matrix A. The histogram shows the importance of different failure modes in percentage. Causality matrix B shows the relative importance of attributes for lathe machine [6].

The assigned values of severity in normalised form is given in matrix below –

$$A = \begin{array}{c} \\ HS \\ TS \\ C \\ FM \\ ES \\ HS \\ CS \end{array} \begin{array}{c} \begin{array}{cccc} CD & FB & CF & LS \end{array} \\ \left[\begin{array}{cccc} 0.5 & 0.44 & 0.5 & 0.33 \\ 0.1 & 0.11 & 0.3 & 0.11 \\ 0.9 & 0.88 & 0.8 & 0.77 \\ 0.2 & 0.22 & 0.4 & 0.11 \\ 1.0 & 1.0 & 1.0 & 1.0 \\ 0.2 & 0.22 & 0.4 & 0.11 \\ 0.3 & 0.33 & 0.5 & 0.22 \end{array} \right] \end{array}$$

		CD	FB	CF	LS
B =	CD	---	0.9	0.3	1.0
	FB	0.8	---	0.2	0.9
	CF	0.7	0.8	---	1.0
	LS	0.7	0.8	0.2	---

The severity values from matrix A of each sub system are substituted in diagonal element of matrix B. The machine tool failure causality indices (MTFCI) are calculated for each sub system by using MATLAB program after putting the severity values of each sub system in matrix B. The MTCFCI values of each sub system are given below –

Electrical system = 7.118
Carriage = 5.376
Head stock = 2.834
Coolant system = 2.469
Feed mechanism = 2.056
Hydraulic system = 2.056
Tail stock = 1.771

SAW Method for calculating MTFCI – For using this method weights are to be assigned to the different failure modes. The weights are decided after normalising the percentage failure data shown in Fig 4. The weights for component damage, fuse burnt, circuit fault and looseness are 0.26, 0.30, 0.07 and 0.37 respectively. The equation (1) is used to find out the index.

Electrical system =1*0.26+1*0.30+1*0.07+1*0.37
= 1.00
Carriage
=0.9*0.26+0.88*0.30+0.8*0.07+0.77*0.37
= 0.838
Headstock
=0.55*0.26+0.44*0.30+0.5*0.07+0.33*0.37
= 0.432
Coolant system
= 0.3*0.26+0.33*0.30+0.5*0.07+0.22*0.37
= 0.293
Feed mechanism
=0.2*0.26+0.22*0.30+0.4*0.07+0.11*0.37
= 0.186
Hydraulic system
=0.2*0.26+0.22*0.30+0.4*0.07+0.11*0.37
= 0.186
Tailstock
=0.1*0.26+0.11*0.30+0.3*0.07+0.11*0.37
= 0.120

WPM Method for calculating MTFCI – The weights assigned for component damage, fuse burnt, circuit fault and looseness are 0.26, 0.30, 0.07 and 0.37 respectively. The equation (2) is used to find out the index.

Electrical system = $1.0^{0.26}+1.0^{0.30}+1.0^{0.07}+1.0^{0.37}$
= 4.00
Carriage = $0.9^{0.26}+0.88^{0.30}+0.8^{0.07}+0.77^{0.37}$
= 3.827
Headstock = $0.5^{0.26}+0.44^{0.30}+0.5^{0.07}+0.33^{0.37}$
= 3.232
Coolant system
= $0.3^{0.26}+0.33^{0.30}+0.5^{0.07}+0.22^{0.37}$
= 2.972
Feed mechanism
= $0.2^{0.26}+0.22^{0.30}+0.4^{0.07}+0.11^{0.37}$
= 2.672
Hydraulic system
= $0.2^{0.26}+0.22^{0.30}+0.4^{0.07}+0.11^{0.37}$
= 2.672
Tailstock = $0.1^{0.26}+0.11^{0.30}+0.3^{0.07}+0.11^{0.37}$
= 2.426

3.2 Calculation of indices of drilling machine

The drilling machine has been classified into various sub systems as shown in Fig 5. The sub systems of drilling machine are Spindle (S), Table (T), Chuck (C), Pulley (P), Electrical system (ES), Feed mechanism (FM) and Coolant system (CS). The failure data has been collected from KKE Wash system Pvt Ltd, Nagpur. The failure frequency and down time have been taken into consideration for deciding critical sub system of drilling machine in this investigation.

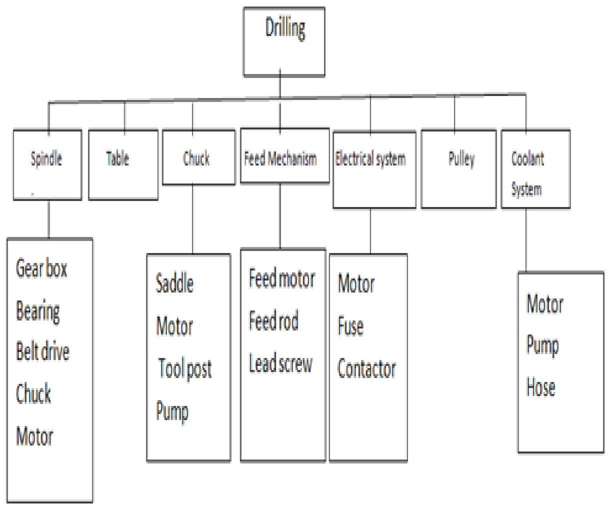

Fig 5 – Classification of drilling sub systems

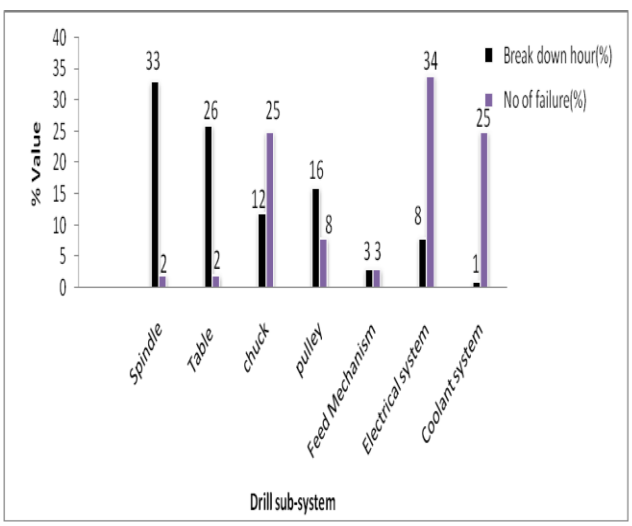

Fig 6 – Failure frequency and down time of drilling machine sub system

The failure data received from industry is shown in Fig 6 & 7. Based on the failure data given in Fig 6, the severity judgement values in normalised form are assigned to the failure causes and these values are given in the matrix A. The histogram shown in Fig 7 shows the importance of different failure modes in percentage. Causality matrix B shows the relative importance of attributes for drilling machine.

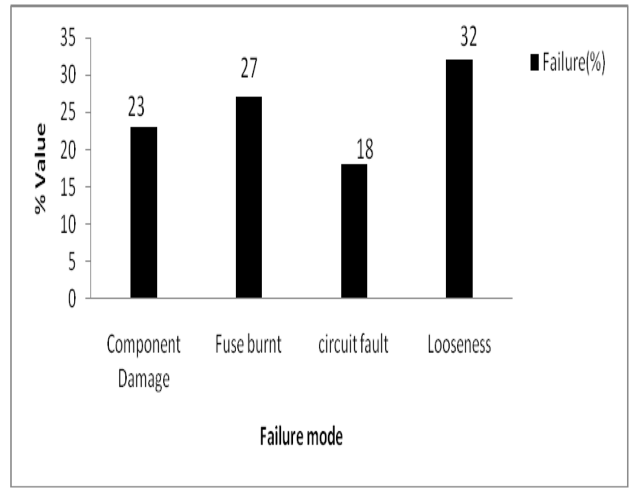

Fig 7 – Histogram showing the different failure modes of drilling machine

The assigned values of severity in normalised form is given in matrix below –

A =

	CD	FB	CS	LS
S	0.1	0.1	0.1	0.11
T	0.1	0.1	0.1	0.11
C	0.8	0.9	0.9	0.88
P	0.3	0.3	0.4	0.22
FM	0.1	0.1	0.1	0.11
ES	1.0	1.0	1.0	1.0
CS	0.8	0.9	0.9	0.88

The severity values from above matrix A of each sub system are substituted in diagonal element of below matrix B. The machine tool failure causality indices (MTFCI) are calculated for each sub system by using MATLAB program after putting the severity values of each sub system in matrix B. Relative importance of attributes is assigned by using the number of failures shown in Fig 7 and it is given in matrix form below.

B =

	CD	FB	CF	LS
CD	---	0.8	0.7	0.7
FB	0.8	---	0.8	0.8
CF	0.7	0.7	---	0.6
LS	0.9	0.9	1.0	---

The MTFCI values of each sub system is calculated using matrix approach and it is given below –

Electrical system = 11.7
Coolant system = 9.89
Chuck = 9.88
Pulley = 4.80
Spindle = 3.707
Table = 3.707
Feed mechanism = 3.707

SAW Method for calculating MTFCI –

The weights are decided after normalising the percentage failure data shown in Fig 7. The weights for component damage, fuse burnt, circuit fault and looseness are 0.23, 0.27, 0.18 and 0.32 respectively. The equation (1) is used to find out the index.

Electrical system
= 1.0*0.23+1.0*0.27+1.0*0.18+1.0*0.32
= 1.00
Coolant system
= 0.8*0.23+0.9*0.27+0.9*0.18+0.88*0.32
= 0.870
Chuck
=0.8*0.23+0.9*0.27+0.9*0.18+0.88*0.32
= 0.870
Pulley
= 0.3*0.23+0.3*0.27+0.4*0.18+0.22*0.32
= 0.292
Spindle
= 0.1*0.23+0.1*0.27+0.1*0.18+0.11*0.32
= 0.103
Table
= 0.1* 0.23+0.1*0.27+0.1*0.18+0.11*0.32
= 0.103
Feed mechanism
= 0.1*0.23+0.1*0.27+0.1*0.18+0.11*0.32
= 0.103

WPM Method for calculating MTFCI –

The weights assigned for events in this method are same as used in SAW method. The equation (2) is used to find out the index.

Electrical system
$= 1.0^{0.23}+1.0^{0.27}+1.0^{0.18}+1.0^{0.32}$
= 4.00
Coolant system
$= 0.8^{0.23}+0.9^{0.27}+0.9^{0.18}+0.88^{0.32}$
= 3.863
Chuck $= 0.8^{0.23}+0.9^{0.27}+0.9^{0.18}+0.88^{0.32}$
= 3.863
Pulley $= 0.3^{0.23}+0.3^{0.27}+0.4^{0.18}+0.22^{0.32}$
= 2.945
Spindle $= 0.1^{0.23}+0.1^{0.27}+0.1^{0.18}+0.11^{0.32}$
= 2.280
Table $= 0.1^{0.23}+0.1^{0.27}+0.1^{0.18}+0.11^{0.32}$
= 2.280
Feed mechanism
$= 0.1^{0.23}+0.1^{0.27}+0.1^{0.18}+0.11^{0.32}$
= 2.280

3.3 Calculation of indices of press brake machine

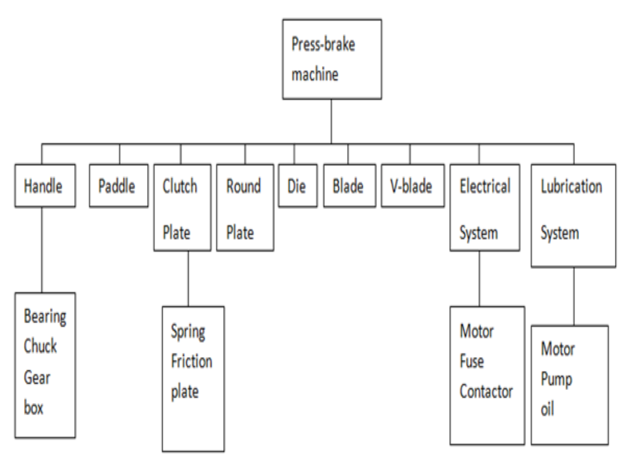

Fig 8 – Classification of press brake sub systems

The press brake machine has been classified into various sub systems as shown in Fig 8. The sub systems of press brake machine are Handle (H), Paddle (P), Clutch plate (CP), Round blade (RB), Electrical system (ES), Die (D), Blade (B), V-belt (VB) and Lubrication system (LS). The failure frequency and down time have been taken into consideration for deciding the critical sub system of machine tool. The data has been collected from Onkar Furnitech, Nagpur.

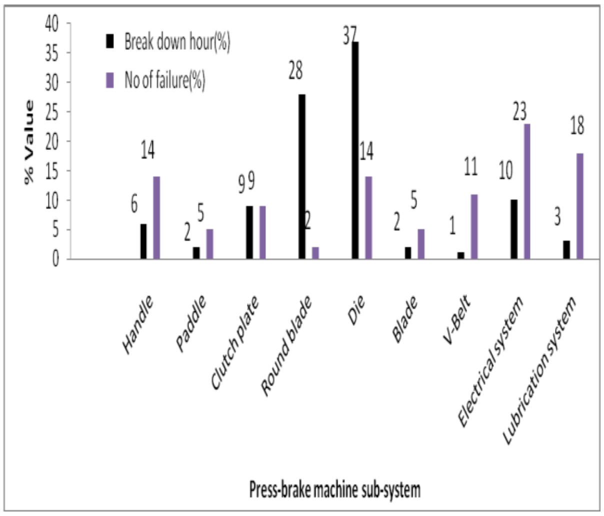

Fig 9 – Failure frequency and down time of press brake machine sub systems

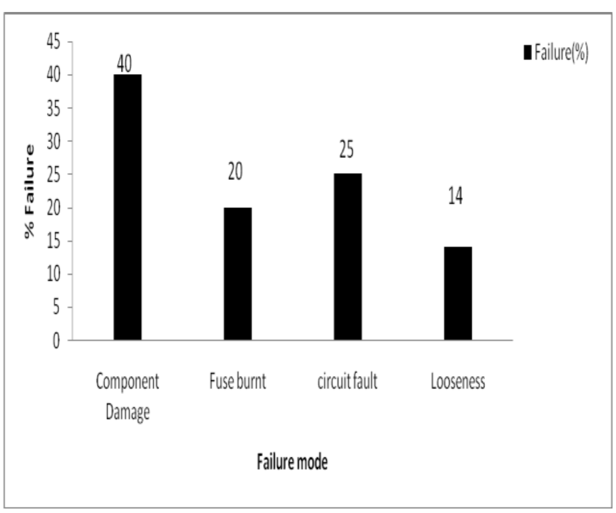

Fig 10 – Histogram showing the different failure modes of press brake machine

The failure data received from industry is shown in Fig 9 & 10. Based on the failure data given in Fig 9, the severity judgement values in normalised form are assigned to the failure causes and these values are given in the below matrix A. The histogram shown in Fig 10 shows the importance of different failure modes in percentage. Causality matrix B shows the relative importance of attributes for press brake machine.

A =

	CD	FB	CF	LS
H	0.66	0.7	0.66	0.7
P	0.16	0.3	0.22	0.3
CP	0.33	0.5	0.44	0.5
RB	0.16	0.1	0.11	0.1
D	0.66	0.7	0.66	0.7
B	0.16	0.3	0.22	0.3
VB	0.5	0.6	0.44	0.6
ES	1.0	1.0	1.0	1.0
LS	0.83	0.9	0.77	0.8

B =

	CD	FB	CF	LS
CD	---	1.0	0.9	1.0
FB	0.5	---	0.8	0.5
CF	0.6	0.9	---	0.6
LS	0.4	0.7	0.6	---

The machine tool failure causality indices (MTFCI) are calculated for each sub system by using MATLAB program after putting the severity values of each sub system in matrix B. Relative importance of attributes is assigned by using the number of failures shown in Fig 10 and it is given in the above matrix B.

The MTFCI values of each sub system is calculated using matrix approach and it is given below –

Electrical system = 8.47
Lubrication system = 6.547
Die = 5.31
Handle = 5.31
V- Belt = 4.319
Clutch plate = 3.75
Blade = 2.817
Paddle = 2.817
Round blade = 2.328

SAW Method for calculating MTFCI – The weights are decided after normalising the percentage failure data shown in Fig 10. The weights for component damage, fuse burnt, circuit fault and looseness are 0.4, 0.2, 0.25 and 0.15 respectively. The equation-2 is used to find out the index.

Electrical system
= 1.0*0.4+1.0*0.2+1.0*0.25+1.0*0.15
= 1.0
Lubrication system
= 0.83*0.4+0.9*0.2+0.77*0.25+0.8*0.15
= 0.825
Handle = 0.66*0.4+0.7*0.2+0.66*0.25+0.7*0.15
= 0.674
Die = 0.66*0.4+0.7*0.2+0.66*0.25+0.7*0.15
= 0.674
V- Belt = 0.5*0.4+0.6*0.2+0.44*0.25+0.6*0.15
= 0.526
Clutch plate
= 0.33*0.4+0.5*0.2+0.44*0.25+0.5*0.15
= 0.406
Blade = 0.16*0.4+0.3*0.2+0.22*0.25+0.3*0.15
= 0.218
Paddle = 0.16* 0.4+0.3*0.2+0.22*0.25+0.3*0.15
= 0.218
Round Blade
= 0.16*0.4+0.1*0.2+0.11*0.25+0.1*0.15
= 0.131

WPM Method for calculating MTFCI –
The weights assigned for events in this method are same as used in SAW method. The equation (2) is used to find out the index. The machine tool indices of press brake machine are given below –

Electrical system = $1.0^{0.4}+1.0^{0.2}+1.0^{0.25}+1.0^{0.15}$
= 4.0
Lubrication system
= $0.83^{0.4}+0.9^{0.2}+0.77^{0.25}+0.8^{0.15}$
= 3.817
Handle = $0.66^{0.4}+0.7^{0.2}+0.66^{0.25}+0.7^{0.15}$
= 3.627
Die = $0.66^{0.4}+0.7^{0.2}+0.66^{0.25}+0.7^{0.15}$
= 3.627
V- Belt = $0.5^{0.4}+0.6^{0.2}+0.44^{0.25}+0.6^{0.15}$
= 3.401
Clutch plate = $0.33^{0.4}+0.5^{0.2}+0.44^{0.25}+0.5^{0.15}$
= 3.228
Blade = $0.16^{0.4}+0.3^{0.2}+0.22^{0.25}+0.3^{0.15}$
= 2.786
Paddle = $0.16^{0.4}+0.3^{0.2}+0.22^{0.25}+0.3^{0.15}$
= 2.786
Round blade = $0.16^{0.4}+0.1^{0.2}+0.11^{0.25}+0.1^{0.15}$
= 2.395

4. Results and Discussion

In the present work two different approaches were used to investigate the critical sub system of machine tools. The first approach is based on the conversion of failure data into matrix form and then machine tool failure causality index (MTFCI) of sub systems is calculated. In the second approach simple additive method (SAW) and weighted product method (WPM) is used to calculate the index of sub systems. The different failure modes of lathe, drilling and press brake machine are shown in Fig 4, 7 and 10. For lathe machine the dominant failure mode is observed to be looseness with 50% failure. For drilling and press brake machine the dominant failure mode is observed to be looseness with 32% and component damage with 40% failure respectively. The graphical representation of number of failure of sub systems of lathe, drilling and press brake machine tool is shown in Fig 3, 6 and 9. The matrix method, SAW method and WPM method were also used to calculate the failure index of sub systems of lathe, drilling and press brake machine. The failure index calculated by GTMA and MADM method was compared for each machine tool. A ranking of sub systems was obtained by each method and it is given in the tables below.

Table 1 – Comparison of failure index of lathe machine

S.No.	Sub systems	GTMA index rank	SAW index rank	WPM index rank
1	Head stock	3	3	3
2	Tail stock	7	7	7
3	Carriage	2	2	2
4	Feed mechanism	6	5	5
5	Electrical system	1	1	1
6	Hydraulic system	5	6	6
7	Coolant system	4	4	4

Table 2 - Comparison of failure index of drilling machine

S.No.	Sub systems	GTMA index rank	SAW index rank	WPM index rank
1	Spindle	7	7	7
2	Table	6	6	6
3	Chuck	3	3	3
4	Pulley	4	4	4
5	Feed mechanism	5	5	5
6	Electrical system	1	1	1
7	Coolant system	2	2	2

Table 3 – Comparison of failure index of press brake machine

S.No.	Sub systems	GTMA index rank	SAW index rank	WPM index rank
1	Handle	4	4	4
2	Paddle	7	7	7
3	Clutch plate	6	6	6
4	Round plate	9	9	9
5	Die	3	3	3
6	Blade	8	8	8
7	V- Belt	5	5	5
8	Electrical system	1	1	1
9	Lubrication system	2	2	2

The ranking was obtained for each sub systems of lathe, drilling and press brake machines. The rank assigned by GTMA, SAW and WPM approach to various sub systems of lathe, drilling and press brake machine is similar as given in Table 1, 2 & 3. All three methods suggest that the Electrical system is the most critical sub system of lathe, drilling and press brake machine tools. The least critical sub systems of lathe, drilling and press brake machines are Tail stock, Feed mechanism and Round blade respectively.

5. Conclusion

The failure analysis of lathe, drilling and press brake machine tools was carried out and critical sub system of these machine tools has been identified based on the failure histories. The most critical sub system of all three machine tools is found to be electrical system, in which motor, fuse and contactor faces frequent problems. The failure of sub system of machine tools can be predicted by the use of proper condition monitoring technique.

6. Acknowledgement

The authors are thankful to KKE Wash system Pvt Ltd and Onkar Furnitech, Nagpur for providing the necessary data on machine tool failure for the present work.

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