ROAD MAINTENANCE MANAGEMENT USING PAVEMENT CONDITION INDEX (PCI) SURVEY

TISARA SITA

Satker P2JN D. I. Yogyakarta,

Directorate General of Highways, Ministry of Public Works and Housing

JL. Ring Road Utara, Maguwoharjo, Depok, Sleman, D. I. Yogyakarta

e-mail: tisarasita@pu.go.id

ABSTRACT

Road maintenance management is a very important issue in the highway management. Existing roads infrastructure on Jl. Prof. Dr. Sardjito and Jl. AM. Sangaji that has been passed by the volume of traffic requires maintenance to prevent severe condition as predicted in design life. Therefore, the objective of this study is to appraise a survey pavement condition method so that the road can be functional more optimal. This study was visually completed by using Pavement Condition Index (PCI) method. It was started by dividing the road into several units length in 30 m for each unit sample. Then, each of the sample unit was observed, evaluate, and analyze to identify the distress type and severity level in order to obtain PCI rating value of the pavement condition. The result of the study showed that the distress types in this research included the corrugation, longitudinal and transverse cracking, patching, polished aggregate, raveling, and potholes. The most distresses that usually occur are longitudinal and transverse cracking, patching and raveling with low severity. From the analysis of PCI method, the rating for both road conditions is excellent; therefore, the suggestion that can be given for those sample roads is preventive maintenance to extend a pavement's life. The road repair options are compared between PCI method by US Army and Asphalt Institute.

Keywords: *Road Maintenance Management, Pavement Condition Index, Road Condition, Pavement's Life, Distress Type*

1. INTRODUCTION

Road maintenance management is a very important issue in the management of the highway. Existing road infrastructure that has been passed by the volume of traffic vehicle would have decrease quality (structural and functional) as predicted in design life. Therefore, road maintenance program requires good planning and adequate funding that is continuous, so that the maintenance system can be properly selected and applied optimally. Data analysis and evaluation of pavement performance for a certain project objectives require accuracy measurements. Mechanism of collecting data is visually to detect and analyze the road condition to obtain representative data as an input to define a strategy and priority programs. The output of this road maintenance management program will be referred for treatment decision making of road condition.

Roads in Sleman and Yogyakarta will be the focus of this study, particularly Jl. Prof. Dr Sardjito (Mirota Kampus intersection to SMK 2 Yogyakarta intersection) and Jl. AM. Sangaji (SMK 2 Yogyakarta intersection to the Tugu Yogyakarta intersection), it can be seen in Figure 1 and Figure 2. The volume of traffic is fairly high at this location, especially at the intersection of Tugu as one of the tourist spots and a connecting road to Jl. Malioboro. Moreover at Jl. Prof. Dr Sardjito and Jl. AM. Sangaji is a connector road to the Gadjah Mada University and to various important locations in the city of Yogyakarta. Pavement condition surveys give an indication of the serviceability of the road pavements and also the physical condition of the assets. It is referred to as the collection of data to determine the ride quality and structural integrity of a road segment. They are based on observations by surveyors as well as measurements of pavement roughness, surface distress, skid resistance, deflection, among others. Condition ratings may be done manually or through automated means. The choice of whether automated or manual depends on an agency's priorities and its available resources. The condition rating for a particular section is chosen from a scale, which may range from 0 to 100, 0 to 5 or even 0 to 99. Damage appears slowly at first, and then gradually accelerates, accumulating to become visible as structural distress and tangible as ride quality reduced. If distress is observed and corrected in a timely manner, low cost strategies will restore the road to nearly its original condition. However, if early treatment is neglected or postponed, the accumulated damage will require a more costly repair treatment. Recognizing that damage accumulation and acceleration is a key to understanding the need for early, low-level, low-cost preventive maintenance treatments.

1.1 Problem of Study

Main problems in this research are:

a. What kind of distress that obtained on Jl. Prof. Dr Sardjito and Jl. AM. Sangaji?
b. What are PCI values on Jl. Prof. Dr Sardjito and Jl. AM. Sangaji?
c. How are the road conditions rating on Jl. Prof. Dr Sardjito and Jl. AM. Sangaji?
d. What are the best maintenance strategies that can be determined?
e. What are the repair options of each distress type that can be obtained?

1.2 Objectives

This research focused in the main objectives mentioned below:

a. Investigate and evaluate the asphalt pavement defects by using pavement condition index (PCI),
b. Estimate the maintenance options.

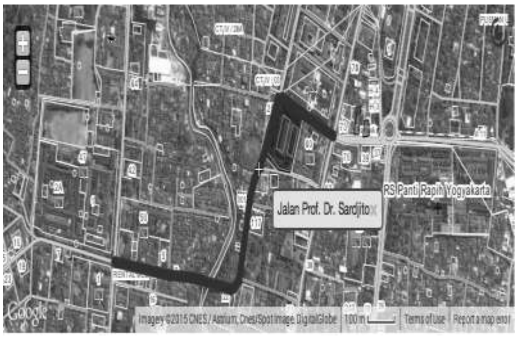

Figure 1. Survey location: Jl. Prof. Dr. Sardjito

Figure 2. Survey location: Jl. AM. Sangaji

1.3 Benefits

Besides the main objectives of the identified problem, there are also additional benefits from this project.

a. Through this survey it can be analyzed how are the PCI value and the rating conditions of the roads on the research location,
b. The proposing road maintenance strategies can be determined,
c. The repair options of each distress type can be obtained,
d. Further, based on the analysis, the measurements that can be taken to improve road performance can be acquired.

2. THEORITICAL BASE

2.1 Pavement Condition Index (PCI)

Pavement Condition Index (PCI) is a numerical rating of the pavement condition that ranges from 0 to 100 with 0 being the worst possible condition and 100 being the best possible condition (ASTM D6433 – 07, 1999). Pavement Condition Index is the most precise index in many pavement evaluation studies. PCI incorporates data from 19 different kinds of pavement distresses as well as their severity and quantity. Furthermore, it gives an insight to the causes of distresses and the relation between pavement deterioration and climatic and/or loading conditions. Therefore, it provides an index of the pavement's structural integrity, as well as surface operational condition. PCI index is extensively used in pavement condition surveys for airfield pavement, roads and parking lots and has gained popularity among the pavement experts (Zultuom, 2011). Federal Aviation Administration (F.A.A.), U.S. Air Force, American Public Works Association (APWA) and many other agencies worldwide accept this method for pavement condition assessment. More details on PCI method are available in ASTM D6433 – 07 (1999): Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys. PCI is the only pavement-rating index that has gained an ASTM standard designation.

In PCI calculation, pavement deterioration rate is a function of distress type, distress severity, and density of distress. For each type, each level and extent of damage according to some nomographs a deduct value is obtained. Deduct values indicate the degree of effect that each combination of distress type, severity level, and distress density has on pavement condition. Eventually, a proportion of the sum of these deduct values is subtracted from 100 and the PCI is determined. The value of PCI varies between 100 for a new pavement with no distress to 0 for a failed pavement. Hence, pavements with lower PCI should be given higher priority for maintenance. Pavement quality condition for different values of PCI is illustrated in Figure 3. In AHP modeling, the PCI criterion was divided to 7 sub-criteria. Using this evaluation index also enables decision makers to account for pavement life cycle costs, by introducing the critical point. Critical PCI is the PCI after which the pavement begins to deteriorate rapidly. Therefore, it would be a wise and prudent decision to keep all the sections above this point. A sample of deterioration model and rate of changes in PCI during years was also published for the same case study (Moazami et al., 2011).

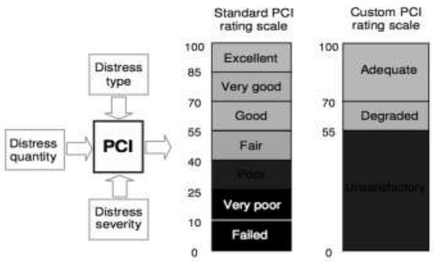

Figure 3. Numerical representation of PCI and pavement quality condition

The PCI is normally conducted annually in order to evaluate changes that occur in a road network system. It is a subjective method of evaluation based on inspection and observation. The PCI is also an informative tool that shows the current condition of the road network and its deterioration over time as illustrated in Figure 4. Some uses and benefits of PCI include, identifying the need for immediate maintenance and rehabilitation (M & R) (Galehouse et. Al. 2003) of roads; developing a road network preventive maintenance strategies and budgets; and for evaluating pavement materials and designs (see Figure 5).

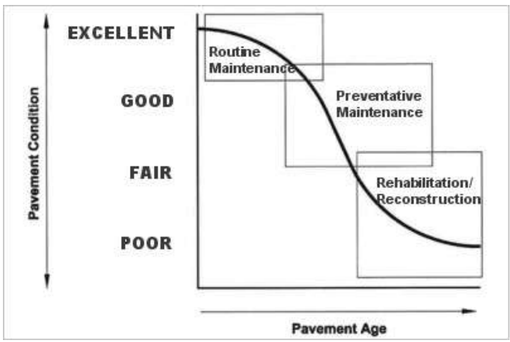

Figure 4. Pavement condition vs age
(Source: Road Millage, August 7, 2012)

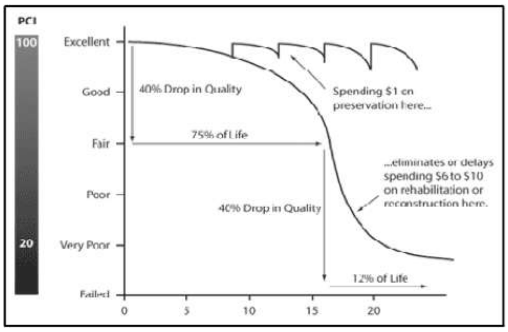

Figure 5. Benefits of M & R as a function of pavement condition (PCI)
(Source: Galehouse et. al. 2003)

2.2 Road Maintenance Strategies

The PCI procedure was developed by the Colorado Division of Aeronautics (2011) to provide a numerical indication of overall pavement condition. During a PCI survey, visible signs of deterioration within a selected sample unit are recorded and analyzed. Distress type, severity, and quantity are all identified and recorded. This information is then used to develop a composite index (PCI number) that represents the overall condition of the pavement in numerical terms, ranging from 0 (failed) to 100 (excellent). In general terms, pavements above a PCI of 65 that are not exhibiting significant load-related distress will benefit from preventive maintenance actions, such as crack sealing and surface treatments. Pavements with a PCI of 40 to 65 may require major rehabilitation, such as an overlay. Often, when the PCI is less than 40, reconstruction is the only viable alternative due to the substantial damage to the pavement structure. This concept, along with the PCI rating scale, is illustrated in Figure 6.

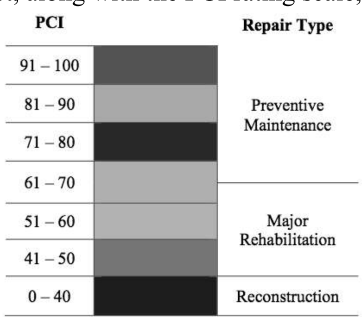

Figure 6. PCI rating scale and recommended repair action
(Source: Colorado Division of Aeronautics, 2011)

The types of distress identified during the PCI inspection provide insight into the cause of pavement deterioration. PCI distress types are characterized as load-related, climate/durability-related, and other (distress types that cannot be attributed solely to load or climate/durability). Each of the distress types and their associated primary cause of distress are identified in Table 1. By knowing the causes of the pavement deterioration, more appropriate repair and rehabilitation alternatives can be identified. Table 2 provides additional information on the likely cause of each distress type and feasible maintenance strategies for addressing each distress type for AC pavements.

Table 1. Distress types and primary distress categories for AC pavements

Pavement Distress Category		
Load-Related	*Climate-Related*	*Other*
Fatigue (Alligator) Cracking	*Block Cracking*	*Bleeding*
*Rutting**	*Joint Reflection Cracking*	*Corrugation*
	Longitudinal and Transverse Cracking	*Depression*
	Patching	*Jet Blast*
	Raveling and Weathering	*Oil Spillage*
		Polished Aggregate
		Shoving
		Slippage
		Swelling

Table 2. Causes of flexible pavement distresses and feasible maintenance strategies

Distress Type	Probable Cause of Distress	Feasible Maintenance Strategies
Alligator Cracking	Fatigue failure of the asphalt concrete surface under repeated traffic loading	If localized, partial- or full-depth asphalt patch. If extensive, major rehabilitation needed.
Bleeding	Excessive amounts of asphalt cement or tars in the mix and/or low air void content	Spread heated sand, roll, and sweep. Another option is to plane excess asphalt. Or, remove and replace.
Block Cracking	Shrinkage of the asphalt concrete and daily temperature cycling; it is not load associated	At low severity levels, crack seal and/or surface treatment. At higher severities, consider overlay.
Corrugation	Traffic action combined with an unstable pavement layer	If localized, mill. If extensive, remove and replace.
Depression	Settlement of the foundation soil or can be "built up" during construction	Patch.
Jet Blast	Bituminous binder has been burned or carbonized	Patch.
Joint Reflection	Movement of the concrete slab beneath the asphalt concrete surface because of thermal and moisture changes	At low and medium severities, crack seal. At higher severities, especially if extensive, consider overlay.
Longitudinal and Transverse Cracking	Cracks may be caused by 1) poorly constructed paving lane joint, 2) shrinkage of the AC surface due to low temperatures or hardening of the asphalt, or 3) reflective crack caused by cracks in an underlying PCC1 slab	At low and medium severity levels, crack seal. At higher severities, especially if extensive, consider overlay options.
Oil Spillage	Deterioration or softening of the pavement surface caused by the spilling of oil, fuel, or other solvents	Patch.
Patching	N/A	Replace patch if deteriorated.
Polished Aggregate	Repeated traffic applications	Aggregate seal coat is one option. Could also groove or mill. Overlay is another option.
Raveling and Weathering	Asphalt binder may have hardened significantly	Patch if isolated. If low-severity, consider surface treatment if extensive. At medium and high severity levels, consider major rehabilitation if extensive.
Rutting	Usually caused by consolidation or lateral movement of the materials due to traffic loads	Patch medium and high severity levels if localized. If extensive, consider major rehabilitation.
Shoving	Where PCC pavements adjoin flexible pavements, PCC "growth" may shove the asphalt pavement	Mill and patch as needed.
Slippage Cracking	Low strength surface mix or poor bond between the surface and next layer of pavement structure	Partial- or full-depth patch.
Swelling	Usually caused by frost action or by swelling soil	Patch if localized. Major rehabilitation if extensive.

2.3 Type of Repair Options

According to Shahin et al. (2005) the PCI method provides repair option according to the distress type and the severity level shown in Table 3. In addition to PCI method, there are so many road maintenance methods such as *Asphalt Institute* method, AASHTO method, and *Austroad* method. Other method to be compared to PCI method in this research is *Asphalt Institute*–MS 16 with the type of repair options shown in Table 4.

Table 3. Type of repair options based on PCI method

No.	Distress Type	Type of Repair Options		
		Low (L)	Medium (M)	High (H)
1	Alligator cracking	Do nothing; overlay	Partial or full depth patch; overlay; reconstruction	Partial or full depth patch; overlay; reconstruction
2	Bleeding	Do nothing	Spreading sand or aggregate	Spreading sand or aggregate
3	Block cracking	crack > 1/8 in (3 mm);crack closure	Crack closure; surface recycling, heater scarify; overlay	Crack closure; surface recycling, heater scarify; overlay
4	Corrugation	Do nothing	Reconstruction	Reconstruction
5	Depression	Do nothing	Leveling; partial or full-depth patching;	Leveling; partial or full-depth patching;
6	Jet Blast			
7	Joint reflection cracking	Crack closure > 1/in (3 mm)	Crack closure; partial-depth patch	partial-depth patch, reconstruction, joint
8	Longitudinal and Transverse Cracking	Width of crack closure > 1/8 in (3 mm);	Crack closure	Crack closure; partial-depth patch
9	Oil Spillage			
10	Patching and utility cut patching	Do nothing	Do nothing, reoverlay	Do nothing, reoverlay
11	Polished aggregate	Do nothing; surface treatment; overlay; scrab and overlay	Do nothing; surface treatment; overlay; scrab and overlay	Do nothing; surface treatment; overlay; scrab and overlay
12	Raveling and Weathering	Do nothing; Closure surface; surface treatment..	Closure surface; surface treatment.; overlay	Surface treatment; overlay; recycling; reconstruction.
13	Rutting	Do nothing; scrab and overlay	Levelling or partial; or full depth patch; scrab and overlay	Levelling or partial; or full depth patch; scrab and overlay
14	Shoving	Do nothing; scrab	scrab; partial- or full -depth patch.	scrab; partial- or full -depth patch.
15	Slippage cracking	Do nothing; partial-depth patch.	Partial-depth patch.	Partial-depth patch.
16	Swelling	Do nothing	Do nothing; reconstruction	reconstruction
~~17~~	Potholes	Do nothing; partial or full-depth patch	partial or full-depth patch	full-depth patch

Source: Shahin et al., 2005

Table 4. Type of repair based on Asphalt Institute (MS-16) Method

No.	Distress Type	Repair Option		
		Low (L)	Medium (M)	High (H)
1	Alligator cracking	Slurry seal; surface treatment or skin patching.	Full-strength patch.	Full-strength patch.
2	Bleeding	Seal coat.	Spreading Hot sand; or spreading hot rock screening.	Spreading Hot sand; or spreading hot rock screening.
3	Block cracking	Surface seal.	Asphalt emulsion'slurry; surface treatment or slurry seal; overlay.	Asphalt emulsion'slurry; surface treatment or slurry seal; overlay.
4	Corrugation	Surface treatment	Levelling; milling; overlay	Full-depth patch.
5	Settlement or grade depressions	Surface treatment; micro-surfacing.	Skin patch or full-depth patch;	Skin patch or full-depth patch;
6	Edge cracking	Closure or filling the cracks with asphalt emulsion slurry or mix asphalt sand	Replacement of the shoulder material, installation of drainage	Replacement of the shoulder material, installation of drainage
7	Reflective cracks	Surface treatment (slurry seal or chip seal), seal cracks.	Cleaning and crack closure	Filling with asphalt emulsion slurry or HMA finely graded
8	Linear cracking	Closure or cracks repair	Closure or cracks repair	Closure or cracks repair
9	Utility cut and/or patch failure	Do nothing	Full depth patch	Full depth patch
10	Polished aggregate	Overlay HMA; sand seal or aggregate seal coat.	Overlay HMA; sand seal or aggregate seal coat.	Overlay HMA; sand seal or aggregate seal coat.
11	Potholes	Cleaning and holes closure with cold mix asphalt.	full-depth patch.	full-depth patch.
12	Rutting	Skin patching; micro-surfacing; or chip seal.	Full depth patch or overlay HMA.	Reconstruction
13	Shoving	Surface treatment	Levelling; scrabing; overlay.	Full-depth patch.
14	Slippage cracking	Replacement of the surface patches	Replacement of the surface patches	Replacement of the surface patches
15	Swell	Full-depth patch.	Full-depth patch.	Full-depth patch.
16	Weathering and raveling	Surface treatment (chip seal or slurry seal)	Surface treatment (chip seal or slurry seal)	Surface treatment (chip seal or slurry seal)

Source: Asphalt Institute MS-16, 2001

3. METHODOLOGY

Quantitative research approach is chosen instead over qualitative research. The used data is primary data, and after that the available data is being analyzed. The methodology flow chart for this research can be seen in Figure 7. The data analysis flowchart can be seen in Figure 7.

1. Proposing The Road Maintenance Strategy

The road maintenance strategy is proposed after the road condition rating is obtained. The road maintenance strategy is selected in accordance with Figure 6. Road maintenance priority is determined based on the lowest condition of the road and the highest AADT.

2. Determine The Road Repair Options

Maintenance is an essential practice in providing for the long-term performance and the esthetic appearance of an asphalt pavement. The purpose of pavement maintenance is to correct deficiencies caused by distresses and to protect the pavement from further damage. After road maintenance obtained, then repair options is determined based on the distress type and the severity level that occurs in accordance with Tables 2, 3, and 4.

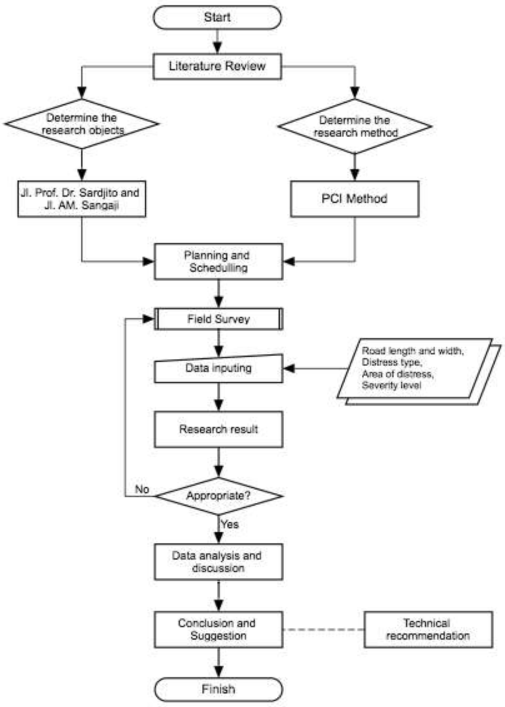

Figure 7. Research methodology flowchart

4. RESEARCH RESULT AND ANALYSIS

4.1 PCI Calculation Results

4.1 Jl. Prof. Dr. Sardjito

PCI calculation results for each sample unit on Jl. Prof. Dr. Sardjito are on Table 5.2, the number of distress types in each sample unit can be seen on Figure 8, while the PCI Rating for Jl. Prof. Dr Sardjito can be found on Figure 9.

Table 5. PCI calculation results of each sample unit on Jl. Prof. Dr. Sardjito

Sample Unit	PCI	Rating	Sample Unit	PCI	Rating	Sample Unit	PCI	Rating
Sample Unit 1	100	EXCELLENT	Sample Unit 12	100	EXCELLENT	Sample Unit 23	100	EXCELLENT
Sample Unit 2	100	EXCELLENT	Sample Unit 13	100	EXCELLENT	Sample Unit 24	100	EXCELLENT
Sample Unit 3	100	EXCELLENT	Sample Unit 14	100	EXCELLENT	Sample Unit 25	100	EXCELLENT
Sample Unit 4	100	EXCELLENT	Sample Unit 15	100	EXCELLENT	Sample Unit 26	91	EXCELLENT
Sample Unit 5	100	EXCELLENT	Sample Unit 16	100	EXCELLENT	Sample Unit 27	97	EXCELLENT
Sample Unit 6	100	EXCELLENT	Sample Unit 17	100	EXCELLENT	Sample Unit 28	100	EXCELLENT
Sample Unit 7	100	EXCELLENT	Sample Unit 18	100	EXCELLENT	Sample Unit 29	100	EXCELLENT
Sample Unit 8	100	EXCELLENT	Sample Unit 19	100	EXCELLENT	Sample Unit 30	100	EXCELLENT
Sample Unit 9	100	EXCELLENT	Sample Unit 20	75	VERY GOOD	Sample Unit 31	100	EXCELLENT
Sample Unit 10	95	EXCELLENT	Sample Unit 21	72	VERY GOOD			
Sample Unit 11	100	EXCELLENT	Sample Unit 22	81	VERY GOOD	**Average**	**97**	**EXCELLENT**

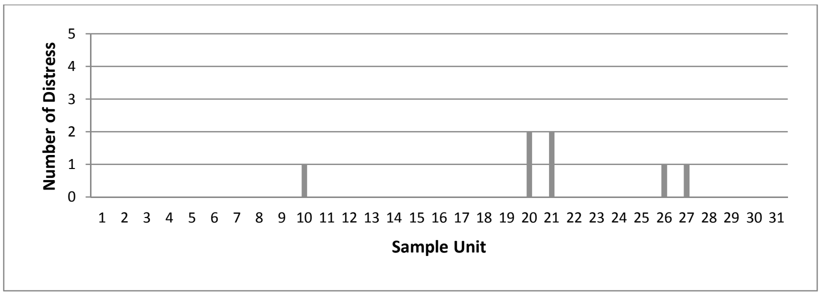

Figure 8. Number of Distress Types in each sample unit on Jl. Prof. Dr. Sardjito

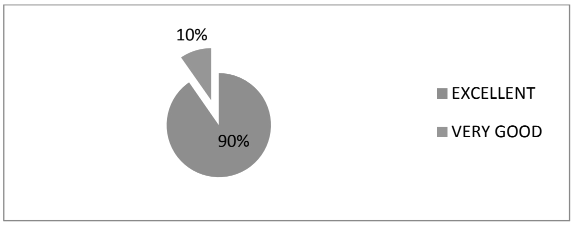

Figure 9. PCI Ratings on Jl. Prof. Dr. Sardjito

4.2 Jl. AM. Sangaji

PCI calculation results for each sample unit on Jl. AM. Sangaji are on Table 6, the number of distress types in each sample unit can be seen on Figure 10, while the PCI Rating for Jl. AM. Sangaji can be found on Figure 11.

Table 6. PCI calculation results of each sample unit on Jl. AM. Sangaji

Sample Unit	PCI	Rating	Sample Unit	PCI	Rating
Sample Unit 1	77	VERY GOOD	Sample Unit 10	80	VERY GOOD
Sample Unit 2	89	EXCELLENT	Sample Unit 11	90	EXCELLENT
Sample Unit 3	87	EXCELLENT	Sample Unit 12	78	VERY GOOD
Sample Unit 4	90	EXCELLENT	Sample Unit 13	90	EXCELLENT
Sample Unit 5	86	EXCELLENT	Sample Unit 14	54	FAIR
Sample Unit 6	84	VERY GOOD	Sample Unit 15	79	VERY GOOD
Sample Unit 7	87	EXCELLENT	Sample Unit 16	79	VERY GOOD
Sample Unit 8	87	EXCELLENT	Sample Unit 17	70	GOOD
Sample Unit 9	86	EXCELLENT	**Average**	**82**	**VERY GOOD**

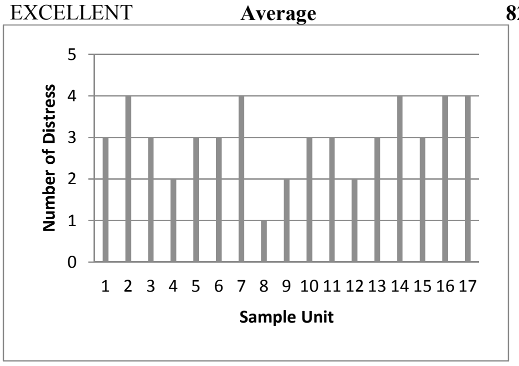

Figure 10. Number of Distress Types in each sample unit on Jl. Prof. Dr. Sardjito

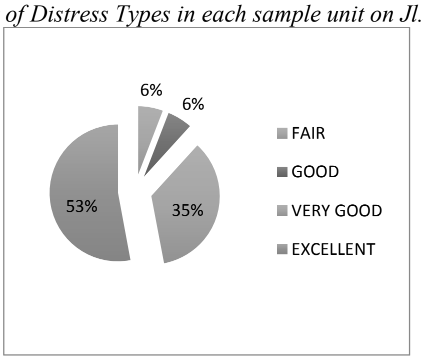

Figure 11. PCI Ratings on Jl. AM. Sangaji

4.3 Jl. Prof. Dr. Sardjito and Jl. AM. Sangaji

The road condition rating based on PCI calculation for both roads, Jl. Prof. Dr. Sardjito and Jl. AM. Sangaji can be seen on Figure 12, while the PCI distribution value for both roads can be found on Figure 13.

Figure 12. *Road condition rating based on PCI calculation on Jl. Prof. Dr. Sardjito and Jl. AM. Sangaji*

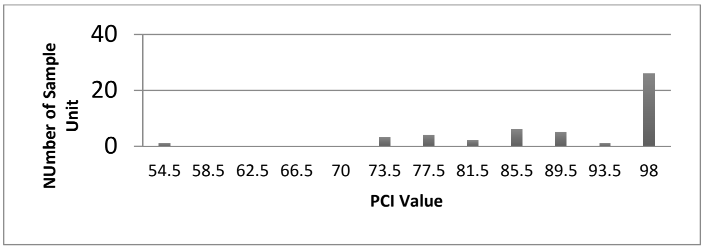

Figure 13. PCI distribution value on Jl. Prof. Dr. Sardjito and Jl. AM. Sangaji

4.2 Road Maintenance Strategies

After determine the road maintenance priority, which presented on Table 7, road maintenance strategies based on the PCI method is selected based on Figure 6. Pavement with PCI values above 65, generally do not show significant distress level (due to load) and can be treated with preventive maintenance such as the closure of cracks and surface maintenance. Pavement with 40-65 PCI values needs rehabilitation, such as overlay. If PCI value is less than 40, then the most viable alternative maintenance to be applied is the reconstruction because the damage that occurs is structural damage. Road maintenance strategy based on the value of the PCI is showed in Table 8.

Table 7. Road maintenance priority based on PCI method

No.	Link	PCI	Rating
1	Jl. AM. Sangaji	82	VERY GOOD
2	Jl. Prof. Dr. Sardjito	97	EXCELLENT

Table 8. Road maintenance strategies based on PCI method

No.	Link	PCI	Rating	Maintenance Strategy
1	Jl. AM. Sangaji	82	VERY GOOD	Preventive Maintenance
2	Jl. Prof. Dr. Sardjito	97	EXCELLENT	Preventive Maintenance

The importance of choosing the right maintenance strategy will have an impact on the resources to be spent, such as costs, labour, tools, and time. The precision maintenance strategy needs to be taken with a rational basis. PCI illustrates the maintenance strategy selection related to PCI value and time as shown in Figure 14.

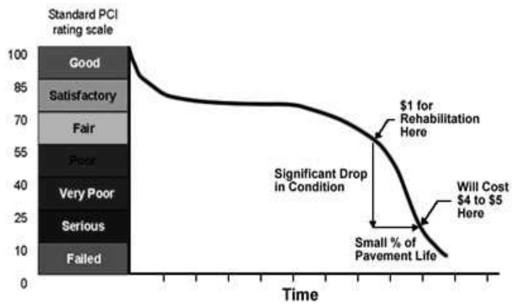

Figure 14. PCI rating vs dan Time
(Colorado State University, 2013)

Pavement in fair condition needs to be rehabilitated immediately in order not to worsen the condition. Figure 14 illustrates that if it is assumed that pavement design life is 10 years of service, so the required time for pavement of the fair condition becomes failed only takes 1.5 years. Therefore if the road PCI value is 65, it must be rehabilitated, such as thin overlay or patching. If the pavement becomes failed due to late rehabilitation, it takes 4 to 5 times the cost of rehabilitation.

4.3 Road Repair Options

As the road priority maintenance has been completed obtained, the road repair options have to be determined, so the fieldwork can be done immediately. Repairs must be done immediately to prevent the worsen damage, so that the repair options chosen is still appropriate to the type of distress, the severity level, and the quantity of the damage. This is because the damage is affected by time, load, and weather; so the longer it is not repaired, the worse the type, the severity level, and the quantity of damage. Road repair options based on the method of PCI and Asphalt Institute MS-16 can be seen in Table 9 and Table 10. PCI method by The Unified Facilities Criteria (2004) does not consist the distress type as follows: railroad crossing, potholes, bumps and sags, edge cracking, and lane/shoulder drop off. The repair option of pothole in Table 9 is determined by Shahin et al. (2005).

Table 9. Road repair options based on PCI method and Asphalt Institute Method on Jl. Prof. Dr. Sardjito

	Low	**Repair Options**	
	Number of Sample Unit	**PCI**	**Asphalt Institute**
Patching (10)	10, 20, 21, 22, 27	Do nothing	Do nothing
Raveling/ Weathering (12)	20, 21, 22	Do nothing; Closure surface; surface treatment	Surface treatment (chip seal or slurry seal)
*Pothole (17)**	26	Do nothing; partial atau full-depth patch	Cleaning and holes closure with cold mix asphalt.
Distress Type	**Severity Level and Repair Options**		

Distress Type	**Severity Level and Repair Options**			**Severity Level and Repair Options**		
	Low	**Repair Options**		**Medium**	**Repair Options**	
	Number of Sample Unit	**PCI**	**Asphalt Institute**	**Number of Sample Unit**	**PCI**	**Asphalt Institute**
Corrugation (4)	7	Do nothing	Surface treatment	-		
Long. And Trans. Cracking (8)	1, 2, 3, 5, 6, 7, 9, 10, 14, 16, 17	Width of crack closure > 1/8 in (3 mm)	Closure or cracks repair	10	Crack closure	Closure or cracks repair
Patching (10)	1, 2, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15	Do nothing	*Do nothing*	1, 2, 6, 7, 8, 11, 14, 16, 17	Do nothing, reoverlay	Full depth patch
Polished Aggregate (11)	2, 3, 11, 13, 14, 15, 16, 17	Do nothing; surface treatment; overlay; scrab and overlay	Overlay HMA; sand seal or aggregate seal coat.			
Raveling/ Weathering (12)	2, 4, 5, 6, 12, 13, 14, 15, 16, 17	Do nothing; Closure surface; surface treatment	Surface treatment (chip seal or slurry seal)	3, 4, 7, 10, 11, 12, 13, 14, 16	Closure surface; surface treatment; overlay	Surface treatment (chip seal or slurry seal)
Rutting (13)	1	Do nothing; scrab dan overlay	Skin patching; micro-surfacing; or chip seal.			

Table 10. Road repair options based on PCI method and Asphalt Institute Method on Jl. AM. Sangaji

Distress Type	**Severity Level and Repair Options**		
	High	**Repair Options**	
	Number of Sample Unit	**PCI**	**Asphalt Institute**
Long. And Trans. Cracking (8)	9	Crack closure; partial-depth patch	Closure or cracks repair
Patching (10)	10, 12, 17	Do nothing, reoverlay	Full depth patch
Raveling/ Weathering (12)	13, 15	Surface treatment; overlay; recycling; reconstruction	Surface treatment (chip seal or slurry seal)

5. CONCLUSION

From all the discussions from the previous chapter, this section would figure out the conclusion of this research. After conducted an analysis and discussion of the results using the PCI method, the conclusions can be explained as follows.

a. The PCI value of Jl. Prof. Dr. Sardjito is 97, while on Jl. AM. Sangaji is 82.
b. The road condition rating of Jl. Prof. Dr. Sardjito is “Execllent”, while on Jl. AM. Sangaji is “Very Good”.
c. The road maintenance of Jl. AM. Sangaji is higher priority than Jl. Prof. Dr. Sardjito. Both of Jl. Prof. Dr. Sardjito, and Jl. AM. Sangaji only needs preventive maintenance.
d. Both of Jl. Prof. Dr. Sardjito, and Jl. AM. Sangaji only needs preventive maintenance. Effective maintenance can extend a pavement's life. Crack sealing and surface treatments can reduce in aging of asphalt pavement. The provision of necessary equipment for maintenance work in order to raise the level of efficiency of maintenance.
e. PCI method by The Unified Facilities Criteria (2004) should consist the distress type and also the repair options, as follows: railroad crossing, potholes, bumps and sags, edge cracking, and lane/shoulder drop off.
f. Axle-load of vehicles must be controlled for preserving the pavement condition.
g. For Public Works Service of Yogyakarta and Sleman, periodic inspection is necessary to provide current and useful evaluation data. It is recommended that ratings be updated every year. The survey should be conducted in a more thorough and conducted by surveyors who have knowledge and high sense of engineering in assessing the distress. Each surveyor should be trained under the supervision of engineers who have experience in advance to ensure the reliability of data to be obtained.
h. It is necessary to study the application of the preventive maintenance management then compared with corrective maintenance or reactive maintenance, which commonly implemented in Indonesia.

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Vibration Data Classification with Fast Fourier Transform and Neural Network

[1]KUSPIJANI,[2]RICHA WATIASIH,[3]PRIHASTONO,

[123]Department of Electrical Engineering, Bhayangkara Surabaya University

114 Ahmad Yani Surabaya, Jawa Timur, Indonesia

e-mail: [1]anikubhara@gmail.com, [2]richa@ubhara.ac.id,[3]prihastono@ubhara.ac.id,

ABSTRACT

Implementation of vibration data classification method with Neural Network (NN) for electrical compressor mechanical looseness condition was proposed in this paper. With used NN was successfully trained for vibration data classification for three conditions that detected: normally condition, mechanical looseness conditions: screws buffer induction motor compressor were looseness and baseplate was weakness). The input matrix of vibration data from detection with two vibration detector were processed with Fast Fourier Transform (FFT). Vibration data from first vibration detector (LVDT1) 98% was successfully classification and for vibration data from second vibration detector (LVDT2) 99% was successfully classification.

Keyword: Vibration, FFT, NN, Classification

Introduction

Vibration is a representation of the mechanical oscillations at the point of equilibrium. In general, vibration is not desirable because it can weaken and cause unwanted noise such as noise. Excessive vibration in the engine is the beginning of some symptoms of damage to the engine such as Mechanical looseness that is a symptom of damage to the machine that may cause damage to others, such as unbalance and misalignment on the machine, so it will affect the efficiency of the engine work.

The main cause of the mechanical vibration is mechanical looseness, unbalance, misaligment, damage to gear (gearing), the imprecision of coupling (coupling inaccuring), damage to the drive belt, alternating style, style rotor/stator that is not straight, which is not the direction the rotor shafts, rotor shaft damage, and so on. High frequency vibration spectrum contains information on errors that can be followed well in advance of actually affecting the ability of machines to run the job, while the low frequency indicates when damage has occurred (Dimarogonas, 1992).

Linear Variable Differential Transformer (LVDT) used to vibration detector for detection of induction motor mechanical looseness shimptom with fast fourier transform (FFT) method (richa et.el, 2008).

Fast Fourier Transform (FFT)

Fast Fourier Transform (FFT) is an efficient method to compute the Discrete Fourier Transform (DFT). Let $x_0,.....,x_{N-1}$ be the timeseries. The DFT is defined by the formula :

$$X[k] = \sum_{n=0}^{N-1} x(n)\, W_N^{kn} \qquad k = 0,1,\dots,N-1 \quad \text{.......(1)}$$

For this study, the frequency axis is devided into bins that correspond to frequency zones of interest. The magnitudes of the FFT coeffisients in the bins are used as features.

Process calculations directly in the process of computerization can cause quite a while because there are N2 DFT complex multiplication number. In this case to speed up the process of calculation method was used Fast Fourier Transform (FFT). The basis of calculation of Fast Fourier transform calculation process is to remove the existing twin within DFT. One method of komputansi Fast Fourier transform; there is komputansi Butterfly FFT using radix-specific 2.syarat komputansi using the radix-2 FFT Butterfly is that the amount of data must meet the 2n number of fruit. In the method of radix-2 FFT Butterfly there is (N / 2 log2 N) complex multiplication.

Neural Network (NN)

Artificial Neural Network is a representation of man-made to simulate the learning process that occurs in the human brain. The term artificial aids diimplimentasikan use of computer equipment primarily to complete the calculation and storage of information provided during the learning process. Like the human brain, the neural network consists of several interconnected neurons. Information received through the network of neurons will be transformed into the output neuron to another, this relationship is known as the weights. The information is stored on a specific value on the weights. Input is processed by a propagation function that will add up the value of all the weight updating. The sum is then compared with a threshold value (threshold), usually through the activation function of each neuron. If the input passes the threshold value of the neuron and the neuron is activated it will send the output via the output weight of all these neurons are connected, and so on.

Multi Layer Perceptron Networks

Multi Layer Perceptron Networks or Multi Layer Perceptron (MLP) is a Neural Network which is the development of a single layer perceptron. Artificial neural networks with a single layer has its limitations in pattern recognition. Drawback is overcome by adding one or more hidden layers between input and output layers. Multi layer perceptron network architecture as shown in Figure 1 consists of input layer (input layer) is coupled with a bias, hidden layer (hidden layer) plus a bias, and output layer (output layer). Vij is a Xi weights from input units to hidden layer units ZJ, and Wjk is the weight of Z_J hidden layer unit to unit output Yk.

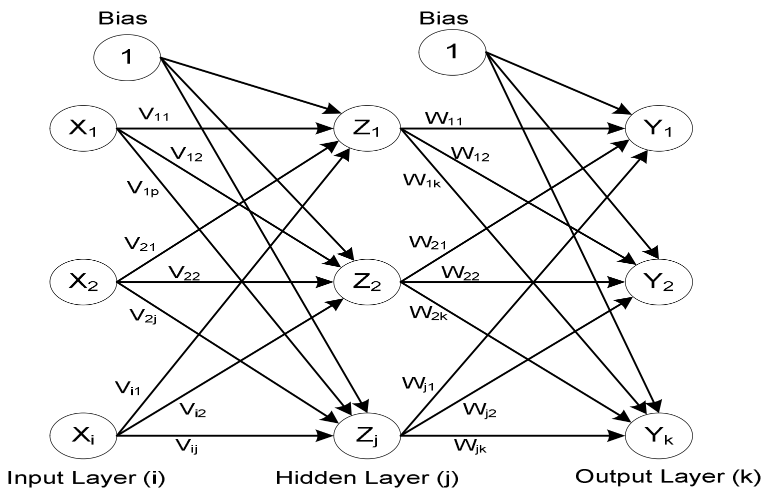


Figure 1. Architecture of multi layer perceptron neural network.

Using the delta learning algorithm called error backpropagation training algoritm. Input argument in the forward direction is fed while the process of learning in addition to utilizing the forward direction of propagation as well take advantage of back propagation direction, when the results do not correspond with the target then the weights updated during the process of learning cycles to obtain the value errror minimum expected or output equal to the target (Muis, 2006).

Training phase is a step to train a NN in a way to change the weight (connection between layers that form the NN through each unit). Problem solving is referred to as the testing process will be conducted after the training process has been completed. Use of more than one hidden layer will require a long training time so that it starts to use a single hidden layer first.

Backpropagation training algorithm includes three stages. The first stage is the advanced stage. Input pattern is calculated forward from input layer to output layer using the specified activation function. The second stage is the stage of retreat.The difference between the net output with the desired target is the error that occurred. These errors are propagated backwards, starting from the line that relates directly to the units in the output layer.

Methodology

Vibration Data processing with FFT

In the FFT calculation, first performed FFT data sorting step is adjusted by the number of data samples used. Data sorted by reflection of the number of binary data sequence is concerned.

By using data that have been sequenced, FFT calculation process followed by 2N-1 komputansi point DFT, then the data is real and the imaginary numbers are obtained computed so that it becomes a value that represents the amplitude of the frequency in question. In the figure 2 (a) is a major program utuk flowchart describing the process of data collection, data processing and vibration using FFT methods teraknir process is showing the vibration spectrum. Whereas in Figure 2 (b) is a sub program for processing vibration data using FFT methods.

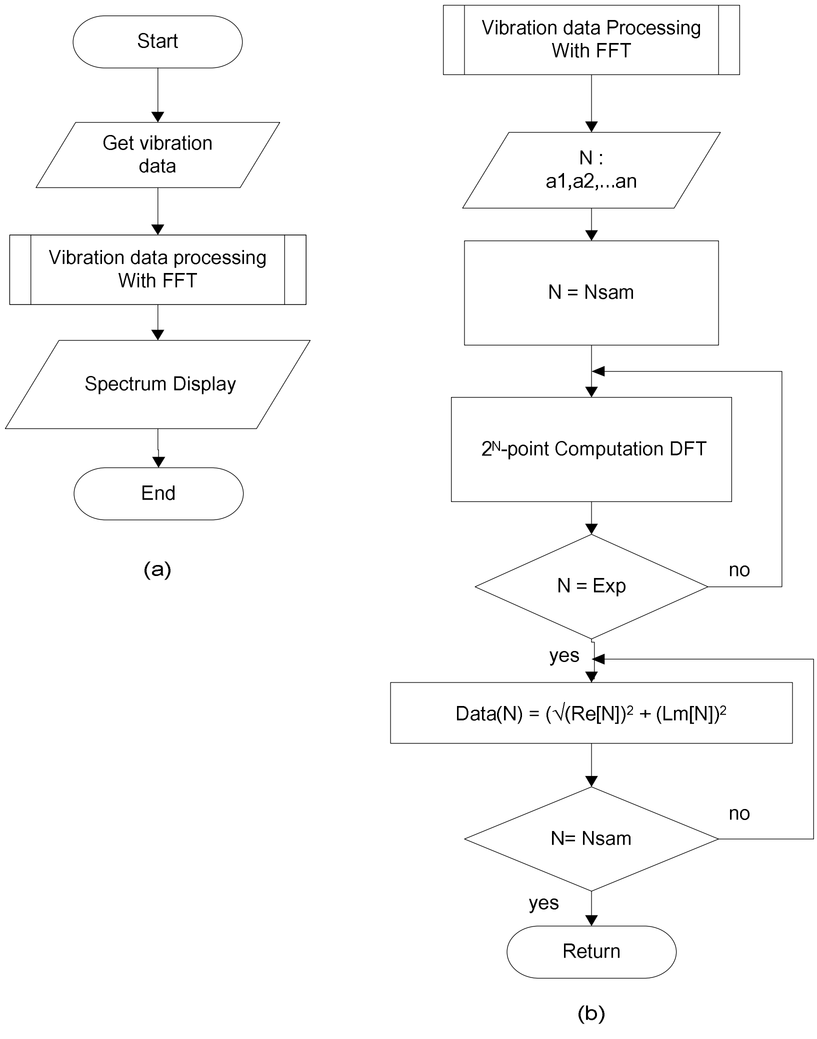


Figure 2. Flowchart of system, (a) main program, (b) sub program of FFT.

Vibration Data Classification with NN

Neural Network (NN) used in this study is many layered perceptron or Multi Layer Perceptron with Backpropagation training of an supervised learning algorithm. As inputs of neural network is the RMS value of the vibration data that have processed with FFT method and they are normalized. The design of Multi Layer Perceptron (MLP) using 3 layers, namely input layer, hidden layer and output layer as shown in figure 3.

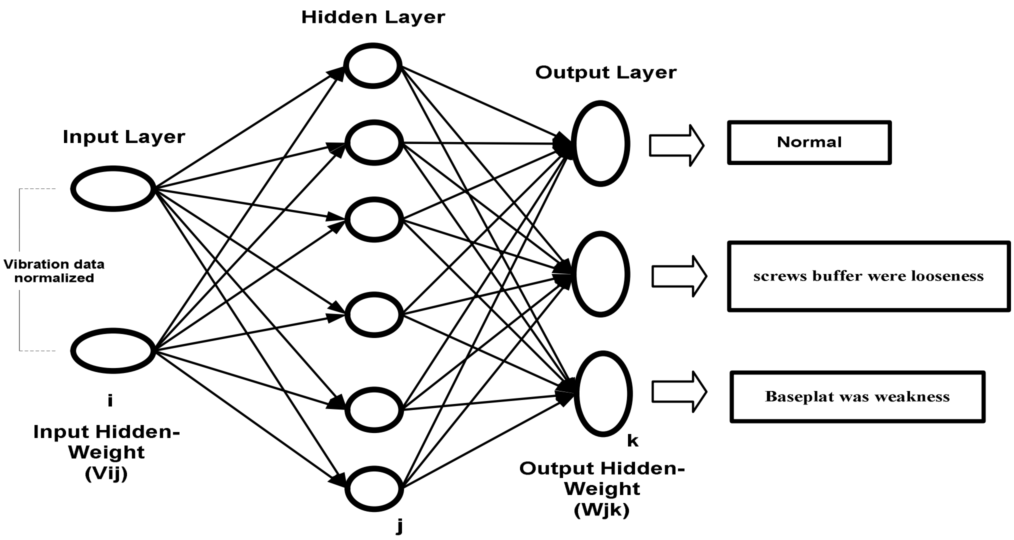


Figure 3. NN-Backpropagation schematic of vibration data classification.

Vibration Data Normalized

Before vibration data used as input in the NN, then the first data on the average vibration into the RMS value normalization is then performed using the equation:

$$Xn = \left(\frac{X}{1.5 \times X\max}\right) \times 0.8 + 0.1 \quad (2)$$

where, X is actual data, Xmax is nilai maximum value of the data and Xn is the normalized data. The maximum value is obtained from vibration data set. The maximum value is multipled by the factor 1.5 so that if vibration data is more than what is considered till now, same neural network can be useful for classification purpose.

At the time of learning in the NN, the highest value of the input variables affect the lower input variable value, the better the data processed by averaging the data input variable vibration before it becomes the input for NN. These data were then normalized within the limits of 0.1 and 0.9 to minimize the effect on the input variables. Limits 0.1 and 0.9 in the select as a replacement for 0 and 1 because 0 and 1 cannot be realized by the activation function (Sigmoid Function). Table 1 is the target/output for each condition is detected.

Table 1. Target/output of tree condition was detected

No.	Condition	O1	O2	O3
1.	Normal	1	0	0
2.	Screws buffer were looseness	0	1	0
3.	Baseplate was weakness	0	0	1

Trainning Process

The parameters used in the ANN:

a. Learning Rate (β)

Learning will accelerate the rate of error reduction, especially in the early stages of learning process JST. Although the constant learning of the ANN can accelerate the learning process, but there are certain conditions which can not achieve the desired minimum error, because the ANN depends on the actual minimum error. When used in a small learning constant of the ANN can achieve the desired minimum error, but the learning process takes a long time (kanata, 2001).

b. Momentum (α)

The larger (β) then the greater the error reduction, but often the error could not reach the global minimum error, so it is used to overcome the learning rate is small, but it requires a large number of iterations. To overcome this momentum can be used to help the process of error reduction on a faster network (Kanata, 2001).

c. Maximum Epoch

The number of iterations affects the length of the learning process, because one requires m iterations of the process, then for n epoch needed nxm process and a process corresponding to the specified intervals. The number of iterations also affects the error, due to an error that tends to get smaller required number of iterations increases.

d. Number of Layer

Layer number used in this studyis 3 layers. The number of cells of each layer are used for training is the result of the FFT vibration data. 4 samples for the learning process vibration data from two vibration sensors (LVDT) for the three conditions was measured as follows: Under normal conditions, the condition of loose bolts and bearings have weak structura lcondition:

- Input Layer = 2 (derived from the results of the FFT of the sensor LVDT1 and the proceeds of the FFT of the Sensor LVDT2).

-Hidden Layer = 10, 12, 14, 16, 18, 20, 22, 24, 25, 26, 28 and 30.

- Output Layer = 3 (normal condition, the condition of the bolts loose and weak structural condition of bearings.

e. Minimum Error

The smaller the error (ideal error = 0) then the network output (vibration data for condition is detected) is almost equal or equal to the target (vibration data for condition is detected). Error related to the number of epoch, the epoch in which the greater the error tends to get smaller.

Table 2 is the parameter that used for trainning process backpropagation-NN for vibration data classification.

Table 2. The parameter of NN-Backpropagation trainning.

No.	Parameter	Value
1.	Epoch Maximum	$1e^{6}$
2.	Mean Square Error (MSE) Minimum	$1e^{-4}$
3.	Learning rate	0,5
4.	Momentum	0,1
5.	Trainning Function	*Feedforward (newff)*
6.	Activation Function	*logsig, logsig,* TRAINGDM

Result and Discussion

Vibration Data Processing

Vibration data is retrieved and then displayed in the form of the spectrum which aims to give an overview spectrum of the original data in the time domain. By using the original vibration data later in the process with the FFT method so that it can be seen more information in the form of the data at low frequencies and high frequencies. On the application of FFT to give a picture of time-frequency vibration signal on the output data in the form of decimated, where the shape is dependent on the detail level based on the data in a state machine of a machine. The first test performed on the three conditions for data sampled as many as 1024 as shown in Figure 4.

Vibration data is retrieved and then displayed in the form of the spectrum which aims to give an overview of the original data in the time domain. By using the original vibration data later in the process with the FFT method so that it can be seen more information in the form of data at low frequencies and high frequencies.

Do some testing times based on some data based on input data, results of some experiments on the spectrum contains the information, to the high frequency is selected as input for the FFT. Then the high frequency vibration spectrum contains information on the errors that can be followed well before they affect the actual capability of the machine to run the job, while the low frequency indicates damages when it has occurred.

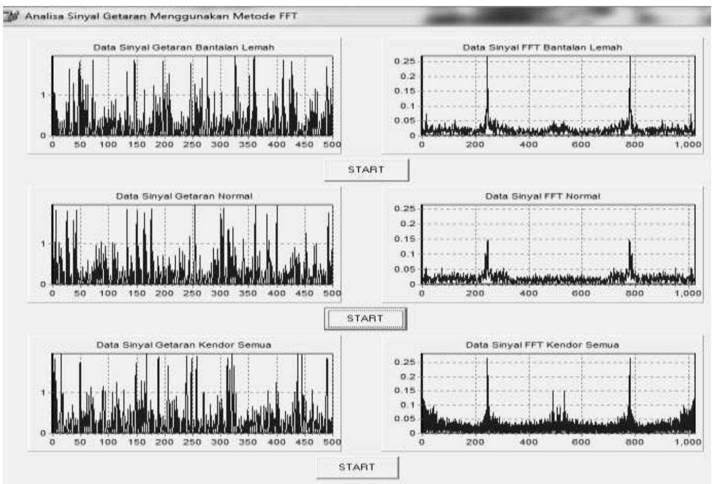


Figure 4. Testing system for the three conditions.

From the results of vibration data processing using the FFT method, the data obtained that there are differences in the spectrum for each condition, the weak bearing conditions, normal conditions Screws buffer were looseness conditions. For vibration data processing results of the testing diberasal the first can be described in which there are significant differences for weak bearing conditions, normal and Screws buffer were looseness all.

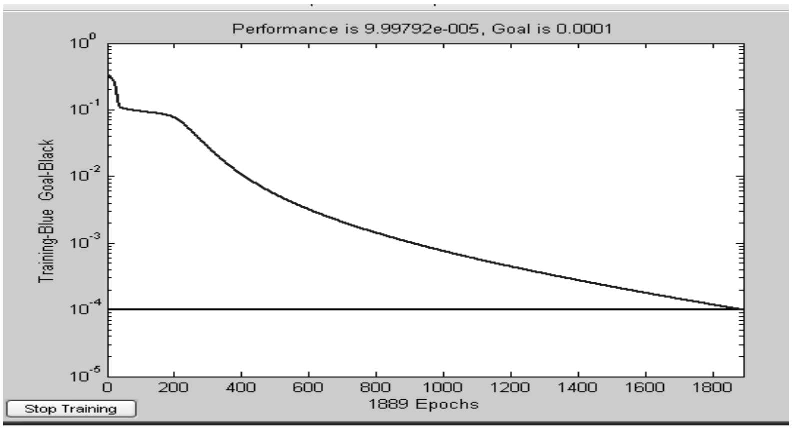
When the normal condition of the vibration signal is more stable than the weak bearing conditions, it occurs because of an increase in the spectral range of data between the data into the data to the 200 and 800, it is because when the pads in a weakened condition, the vibration signal to detect vibrations greater than the vibration signal normal circumstances. conditioned as are normal when it detects vibrations smaller than the bearing vibration signal is weak as all the bearings in tight circumstances. Likewise when all the slack conditions in the state of vibration signals show a large vibration than the vibration signal in a state of weakness and normal bearing seen from the spectrum in the range of data enhancement 200.500, and 800. Of the three trials that have been made of data obtained as shown in Table 4.1 for a gain range of vibration data is based on the vibrational spectrum of the x-axis to the frequency of its amplitude increases.

Table 4.1 Increament in Range Data

Condition	**Experiment**	**Increament in Range Data (0-1024)**		
		250	**500**	**780**
weak bearing	1	0.25	0.05	0.25
Normal		0.15	0.025	0.15
Screws buffer were looseness		0.25	0.10	0.25
Baseplate was weakness	2	0.15	0.10	0.15
Normal		0.10	0.015	0.10
Screws buffer were looseness		0.25	0.13	0.25
Baseplate was weakness	3	0.15	0.10	0.15
Normal		0.10	0.015	0.10
Screws buffer were looseness		0.25	0.14	0.25

Vibration Data Classification With NN

Neural Network (NN) that uses the Backpropagation learning method works in the M-File Matlab7 off-line (simulation). Network architecture using the function "newff" on Matlab7 used for learning. To speed up the process of learning the methods applied learning rate = 0.5 and momentum = 0.1. In the process of learning, the network is doing the learning to achieve the Mean Square Error (MSE) is desired which is 10e-4 with the maximum epoch 10e6. From the results of the learning process that has been done by the NN can be seen that to achieve the desired MSE at the 1889 epoch can be achieved, it is as shown in Figure 4.



Gambar 4. Grafik hubungan error dan epoch untuk jumlah hidden layer 30 neuron.

Figure 5, 6 and 7 are the results of NN, Backpropagation learning for classification of the vibration data LVDT1 and LVDT2. Where in the learning process applied to the function of hidden layer neurons between 10 and 30 to get the right number of hidden layer for classification of vibration data.

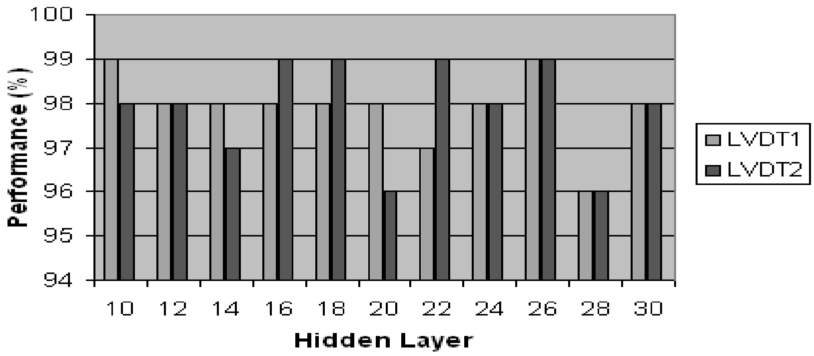


Figure 5. Vibration data classification results for Normal conditions of LVDT1 and LVDT2.

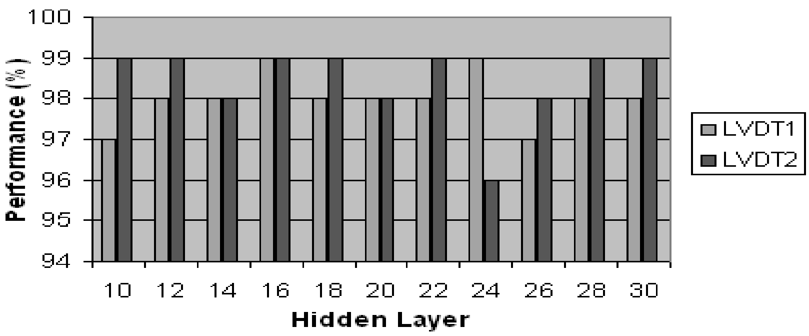


Figure 6. Vibration data classification results for conditions Bolts loose from LVDT1 and LVDT2.

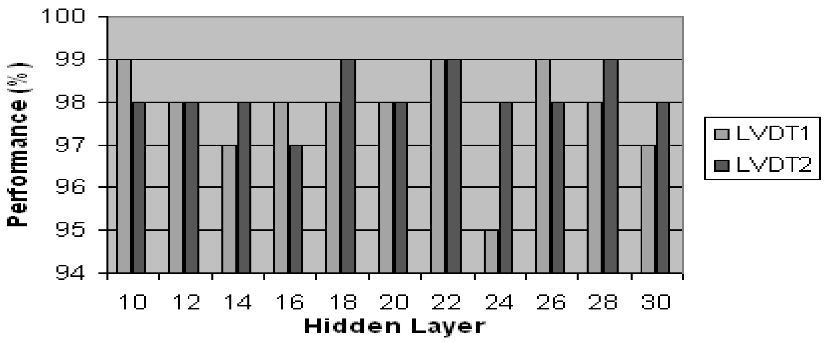


Figure 7. Vibration data classification results for the condition of bearings Structural weak from LVDT1 and LVDT2.

From the results of NN, Backpropagation learning is used for data classification in detecting mechanical looseness vibration is based on the graph shown in Figure 5, 6 and 7 that for the vibration data from sensors LVDT1 successfully classified 98%, while for vibration data from sensors successfully LVDT2 99 % classified on the application of a total of 18 hidden layer neurons.

Conclusion

By applying FFT and NN-Bacpropagation method used for the classification of vibration data from sensors LVDT1 successfully classified 98%, while for vibration data from sensors LVDT2 successfully classified 99% for the three conditions are normal and the condition of mechanical loosesness bolts loose and weak structural bearing conditions.

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