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Diagnosis in Bending Fatigue of Spur Gear Teeth

Hirofumi Sentoku and Takashi Tokuda
Yamaguchi University, Faculty of Engineering
2557 Tokiwadai, Ube-city, Yamaguchi 755, JAPAN

Abstract
Reserch concerning gears included in rotating machines has been reported using the acoustic emission(AE)method,however, almost no researchhas been conducted using the AE method in regardto running gears in a bending fatigue processof spur gear teeth.Therefore, in this report, a power circulating-type gear testing machine was used and AE signals and crack length were measured in the bending fatigue process of case-hardened spur gear. Furthermore ,the envelope of the AE signal was detected and various analysis were carried out in this data.In the course of the experiments,the following results were observed;the AE signal envelope consists mainly of contact frequency component and twice as many as this.;two peaks of AE appear in each tooth contact by the tip corner contact.; as a result of the severe tip corner contact with the sudden increase of crack length,AE signal becomes large.

1.Introduction

It is important in the prevention ofserious accidents and rise of productions to detect abnormalities in the early stages of the process. Up to now abnormalities occuring in rotating machines have been detected by noticing variation of vibration and temparature etc.. - But their dignosis is possible only after the damage has advanced to a considerable degree. For diagnosing the abnormalities in rotating machines, AE has been effectively applied[1].Reserch concerning gears included in rotating machines has been reported using AE method, however, almost no research has been conducted using the AE method in regard to running gears in a bending fatigue process of spur gear teeth. Therefore,in this report, by using a power circulating-type gear testing machine,AE signals and crack length were measured in the bending fatigue process of case-hardened spur gear. Furthermore, the envelope of the AE signal was detected and various analysis were carried out in these data.

2.Test Gear and Method of Experiment

2.1 Test Gear

Test gear is carburized and quenched steel SNC 815.The dimension is shown in Table 1. Hardness distribution in depth direction of gear is shown in Fig.1.

Table 1 Dimension of test gears

		Pinion	Gear
Module	m	4mm	
Pressure angle	α_0	20°	
Number of teeth	z	27	31
Addendum modification coefficient	x	-0.1	0
Facewidth	b	10mm	
Method of finishing teeth		Hobbed	
Accuracy		JIS 4 grade	
Material		JIS SNC 815	
Heat treatment		Carburized & quenched	

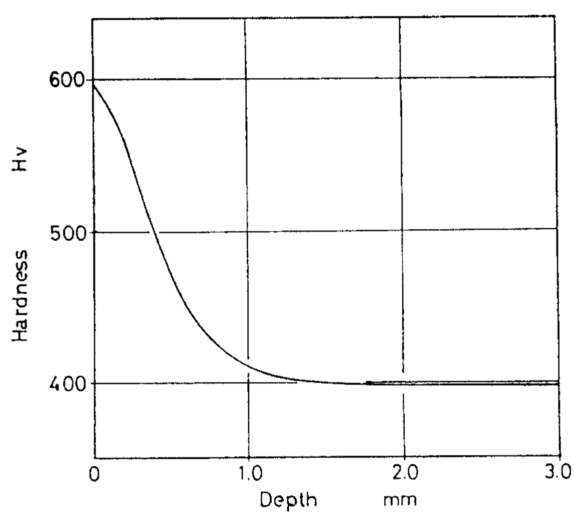

Fig.1 Hardness distribution of test gear tooth

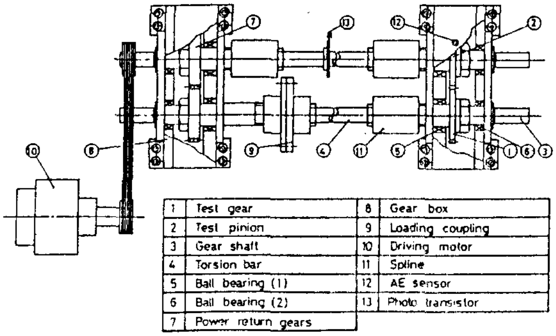

Fig.2 Testing machine

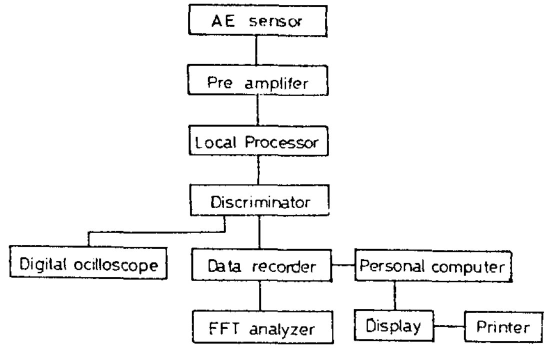

Fig.4 Block diagram for AE measurement

2.2 Method of Experiment

The power circulating-type gear testing machine is shown in Fig.2. The number of revolution of the pinion and gear shaft were 506,441 rpm respectively.About 0.5ℓ/min of oil was poured on the tooth flank. Gears were loaded by a coupling of ⑨ in Fig.2 to give torque. The normal force on the tooth flank Pn was 19.3 kN. Synchronizing signal was measured using a photo transister. To cause a crack, one fillet was grinded by milling machine 2mm from both sides of tooth. By pasting strain gauge of length 0.2mm at critical section of the tooth , the fillet stress of the tensile flank was measured. In order to measure the fillet stress profile in the bending fatigue process ,a strain gauge was pasted on the tooth side of the fillet of the compressive flank.Furthermore, to measure the crack length, the crack gauge shown in Fig.3 was made and pasted on the tooth side of the fillet of the tensile flank. Grids of width 25 μm were placed in sixty rows in a circle and a radius of gauge base agrees with that of the fillet profile.Crack length was measured by the resistance of the crack gauge.An AE sensor was fixed on the gear box with a magnet. Fig.4 shows a block diagram of AE measurement. AE signal was amplified 20 dB by pre amplifier , 30 dB by local processor and 20 dB by discriminator.The signal was band-passed and the AE signal envelope was detected. The signal was recorded in the data recorder and analyzed.

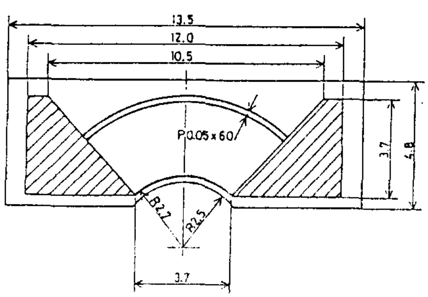

Fig.3 Crack gauge

3.Experimental results and considerations

3.1 Frequency analysis of the AE signal envelope

Fig.5 shows the synchronizing signal at $N=3.48\times10^4$ and a sample of the AE signal envelope profile. The frequency analysis was done about the AE signal envelope at each cycle and the results were shown with a crack length as in Fig.6 . It is known that amplitudes in frequency f= 227.5Hz and 455.0Hz are bigger at each cycle. F= 227.5Hz and 455.0Hz agree with contact frequency and twice as many as this respectively. In the circumference of these frequencies , side lobe which is rotation frequency fr were found. There was not much change to the order of $N=4.13\times10^4$. However, in the neiborhood of $N=4.31\times10^4$ where the crack advances suddenly ,side lobe appear in the wide band.

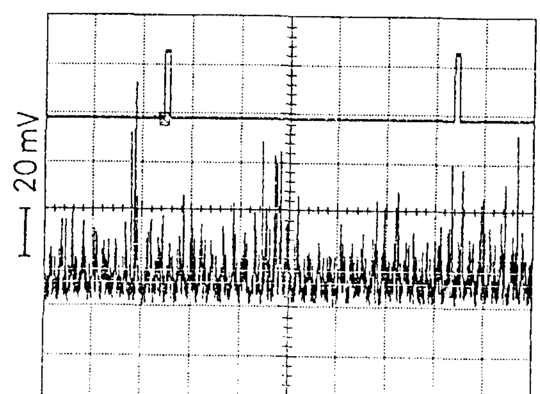

Fig.5 Pulse wave and AE signal envelope

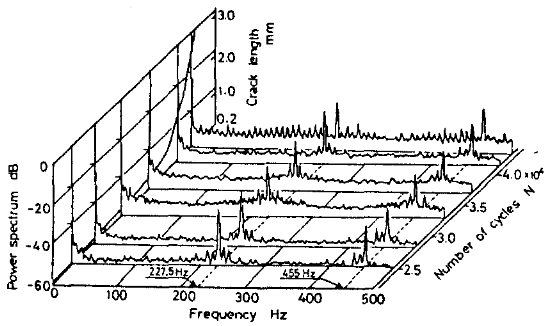

Fig.6 Frequency spectra of AE signal envelope in fatigue process

3.2 The AE signal envelope profile and the fillet stress

Fig.7 shows the fillet stress profile with strain gauge pasted on the tooth side of the fillet of compressive flank and the AE signal envelope profile in the neiborhood of $N=3.48\times 10^4$.The AE signals which were added 100 times in the same period by the syncronizing signal and averaged were put down in the figure together.By this management,the AE signals which didn't syncronize in the rotation of the pinion gear shaft can be excluded. The broken line in this figure shows the fillet profiles shifted as much as one pitch.In the fillet stress profile in the figure , double contact and contact ratio are large. This is considered to have occured by the tip

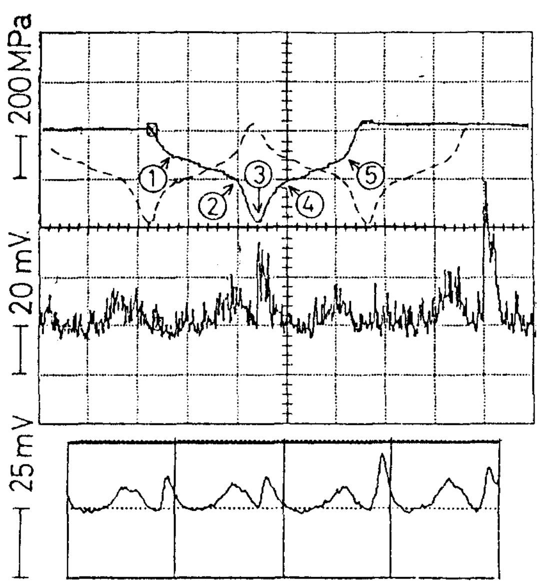

Fig.7 The fillet stress profile and AE signal envelope

corner contact because of large load.In Fig.7, peaks of the AE signal are found at ②,③ and ⑤ of the fillet stress profile. There are two peaks in each tooth contact of the AE signal by the syncronized addition. This is considered as follows. Fig.8 shows the load assignment rate q obtained by the fillet stress of the tensile flank and $\bar{w}$ and $\bar{\theta}$. $\bar{w}$ and $\bar{\theta}$ are the amounts whose relative friction power w and flash temperature by BLOK θ were divided by w_B, θ_B which are the friction power and the flash temperature of ③ in Fig.7 respectively.

$$w = q\mu P_n | v_1 - v_2 | \quad \cdots\cdots (1)$$

$$\theta = 0.83 \frac{q\mu P_n | v_1 - v_2 |}{\sqrt{\lambda\gamma c b}\,(\sqrt{v_1}+\sqrt{v_2})} \quad \cdots (2)$$

But,q:load assignment rate, μ:friction factor , Pn:normal load on tooth surface, v_1, v_2:tangential velocities of gear and pinion respectively, λ:thermal conductively , c:specific heat , b: contact width of Hertz , γ:specific gravity

AE in double contact is considered as composition of AE in each tooth contact[2] , and $\bar{w}$ and $\bar{\theta}$ are added respectively in each of these tooth contacts. In Fig.8, peaks of $\bar{w}$ and $\bar{\theta}$ are in middle of theoretical double contact , but in Fig.7, peaks of the AE signals are at ②,⑤. In these positions, the tip corner of the pinion gear was meshed at,so the relative radius of the curvature of tooth R is very small and the contact width of Hertz in equation (2) becomes nar-

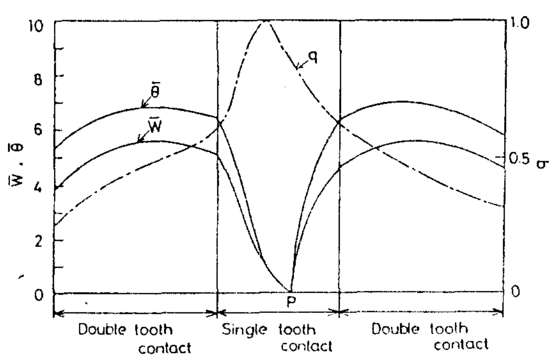

Fig.8 Friction power $\bar{w}$ and temperature $\bar{\theta}$

row and flash temperature becomes very high. It is considered that large Hertzian pressure on tooth flank by the tip corner contact and friction by large slip are occured. Therefore, AE in double contact is the amounts whose AE shown in Fig.8 is put on that by the tip corner contact. As in Fig.8 , $\overline{w}$ and $\overline{\theta}$ are small in theoretical single contact ,but a peak of AE occurs at ③ in Fig.7. This may have been the vigoyous rubbing of the AE on the tooth flank by the tip corner contact of the wheel gear. Marks of the seize were found on the fillet. Therefore,it is considered that two peaks of AE in each tooth contact as shown in Fig.7 are due to the tip corner contact in the border point of single and double contacts.

3.3 AE signal averaged after synchronized addition and crack length

Fig.9 shows the AE signal envelope added in the same period and averaged in the same manner as stated above. The horizontal shaft shows time in one rotation of the pinion gear shaft and the number of gears.The number of gears on which the crack gauge was pasted is 15. It was found in these figures that two peaks of AE appear in each tooth contact . In No.15 tooth , the peak value of AE in the tip corner contact of gear increases gradually as the number of cycle increases, and the peak value becomes very large

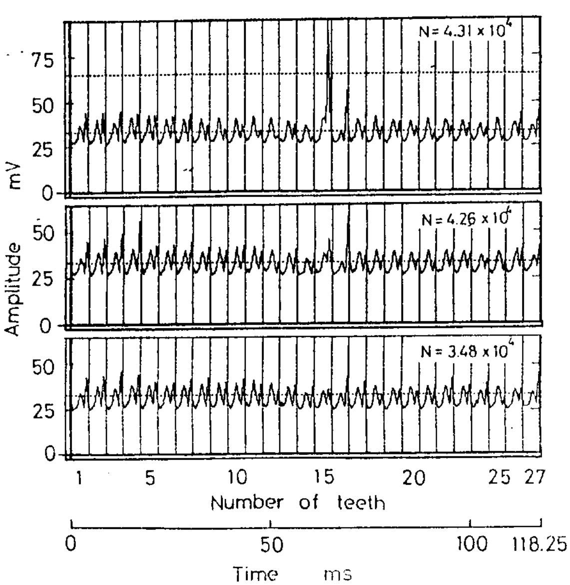

Fig.9 Average of AE signal envelope added in the same period

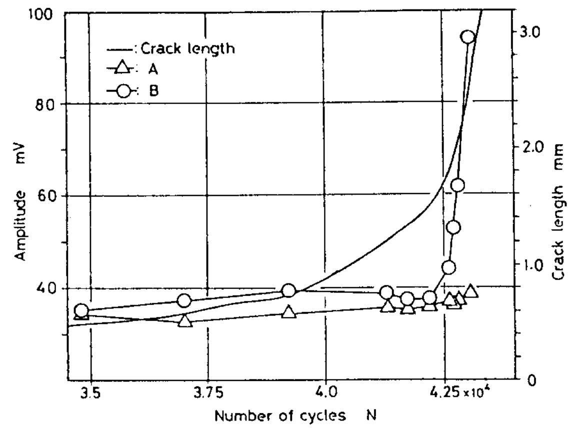

Fig.10 Two peaks of AE signal envelope in fatigue process

in the neiborhood of $N=4.31\times10^4$.Two peak values of AE signal in No.15 tooth (let point A and B be the position of the tip corner contact of pinion and that of wheel respectively.)are shown against the number of the cycle in Fig.10. Crack length is noted in the same figure. In the case of point B, the peak value does not change very much to the order of $N=4.23\times10^4$, but increases suddenly from $N=4.27\times10^4$ with the advance of the crack.However,in point A ,there is no change against the number of cycles very much. This is considered as forrows.In the contact of point A, to mesh on the inclination towards the fillet of No.15,the deflection of the tooth did not change very much against the increase of crack. But, to mesh on the more incliation towards tip of No.15 in point B and be bigger in the load assignment than in point A, the tooth of No.15 deflects greatly with an increase of crack and the stiffness of the tooth becomes small.It is considered that ,because of this,the load assignment of the tooth of No.16 became big, and large load was applied on the tooth flank and the tooth flank was rubbed vigorously by the tip corner contact of the wheel gear.Wider marks of seize were left in the fillet of No.16 than on another teeth.

4. Conclusion

AE signals and crack length were measured in the bending fatigue process of case-hardened spur gear by using the power circulating-type gear testing machine.As a result,it was concluded that:

(1)The AE signal envelope consists mainly of contact frequency component and twice as many as this. In the number of cycle where the crack advances suddenly, side lobe appears in the wide band.

(2)Two peaks of AE appear in each tooth contact. This is considered to have occured because of the tip corner contact.

(3)As the result of the severe tip corner contact by the deflection of tooth with the sudden increase of crack length, AE signal becomes large

References

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