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The Damping Property of Laminated Damping Steel Sheet after Deep Drawing

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Abstract

The damping property of laminated damping steel sheet is affected by shear deformation of viscoelastic layer, a constraint produced by the mutual slip between two steel sheets under a bending vibration mode. So, the bonding of the viscoelastic layer to steel sheets is critical to the damping property.

Sometimes, laminated damping steel sheet becomes unbonded locally from the viscoelastic layer because of an excessive relative slip between two steel sheets caused by a deep drawing.

It was found that by using the transmittance of ultrasonic wave, the unbonded area of laminated damping steel sheet can be detected without cutting it off. The validity of this method was confirmed by the T-Peel test which was conducted after the sheet was cut off.

The damping property measured at the wall of' a deep drawn oil pan, was compared with a one for a laminated damping steel sheet not drawn yet.

It was found that the damping property and the noise reduction effect of a sheet after deep drawing were reduced in reverse proportion to the widening unbonded area.

1 Introduction

Steel sheet panels used for main components of a structure induce, in many cases, vibrations of bending modes and become a source of big noises.

The laminated damping steel sheet is incorporated not only with a normal function of steel sheet but also with a damping characteristic and, therefore, a substantial degree of reduction in vibration and noise can be achieved when it replaces an original steel sheet. This is an attractive feature from the design point of view since a basic structure of design can be retained as it is without making any modifications or alterations. The range of application for the material of this type has been expanded remarkably after an application to a deep drawn component part was made feasible by great improvements achieved in the sheet formability.

There are many covers attached to the exterior of reciprocating engines used in the motor vehicles. They are the major sources of noises and, in particular, an oil pan has been known as being one of the big noise sources.

An example of noise contribution ratio of various engine components is shown in Fig. 1. A press formed steel sheet oil pans are generally used by the Japanese motor industries. Since a press die used for forming an oil pan of original steel sheet can be used without supplementing a major modification and also assisted by improvements achieved in the formability as mentioned above, the use of laminated damping steel sheet for the oil pan production was spread quite rapidly.

Stimulated by such application in massproduction system of the motor industries, applications by other industries were commenced and grew in a short period of time. The consumption of such materials, therefore, has grown in an amazing speed in Japan for the last few years.

The laminated damping steel sheet, however, has problems still to be solved. They are weldability, formability, bolt loosening, loss of bending stiffness, etc. Those problems can be solved not only by the improvement in steel sheets and damping films but also by the special design considerations given to a portion of structure where such a material is used. In order to acquire satisfactory solutions to such problems, it is essential to get a full knowledge of the nature of problem.

In this paper, a consideration will be given to the effect of deep drawing to the damping characteristic of the sheet. This is a critical problem as it is closely associated with a loss of fundamental mechanism of the damping effect. An oil pan is typically a deep drawn component part and can be a good example representing an involvement with this problem. It was quite incidental that the first full scale use of this material in Japan was directly involved with one of the most difficult problems.

2 Shear Deformation of Damping Layer

When a bending deformation is brought to a laminated damping steel sheet in a press operation, the deformations as shown in Fig. 2 takes place in the damping layer due to the tensile or compression deformation similar to the ones given to two steel sheet and the shear deformation caused by the mutual slip appeared between those two sheets.

The damping layer is a film of high polymer resin and, therefore, is able to withstand substantially layer deformation than steel sheets. The tensile and compression deformations on high polymer resin are in the same magnitude as those on surrounding steel sheets and will not create any problems by themselves, however, since the shear deformation of damping layer is formed by a force generated by the mutual slip two of steel sheets and the magnitude is considerably larger, it is sometimes brought into a zone where some problems may start to appear.

As obvious in Fig. 3, damping layer's shear curve has a linear elasticity zone and a plastic deformation zone even though they are not defined as distinctively as a metal. The curve goes through the maximum shear stress point and is terminated by a rupture of layer, that is, a separation. [1] Maximum slip δ_{max} prevailing in such an instance will be in a magnitude inherent to the material and proportional to the thickness of damping layer.

Fig. 4 shows the distribution of mutual slip appeared between two steel sheets of laminated damping steel sheet when it was bent to most fundamental V form by a press. Slits were provided on the side of rectangular piece of laminated damping steel sheet and the rate of slippage between two steel sheets was measured after the piece was bent by a press. Obviously in the figure, the slip becomes largest in the border zone between circular arc and flat flange areas.

Fig. 5 shows the distribution of mutual slip between two steel sheets when a test strip piece is drawn into a channel form. [3] The cross section of the piece is resembled to that of an oil pan. Since the flange zone C~D was held firmly to prevent wrinkling during the formation and the bottom line A~B has a symmetry against the center line which passes through point A, the mutual slips between two steel sheets in those two zones are virtually nil. A large mutual slip appear on the side portion B~C, a portion located between the said two portions, simply because of the right angle bendings provided at both ends of this portion. The magnitude of mutual slip movement varies extensively and complexly while the piece is formed in a press. Details of mechanism, therefore, have not been clarified yet.

When a laminated damping steel sheet is used for an oil pan having a cross section in a form as shown in Fig.5, therefore, the damping layer in the side wall will be subjected to a large shear deformation. Fig. 5 (b) shows that as a die corner radius is increased, the maximum mutual slip becomes smaller. This shows that a shear deformation of damping layer can be reduced by a modification of pressing die. However it results in restricting die radius Rd necessary for securing the width of flat range portion.

As shown in Fig. 6, the damping effect demonstrated by the laminated damping steel sheet in bending vibration mode is brought forth by the shear deformation of high polymer resin layer sandwitched between two steel sheets. Under such circumstance, therefore, if an excessive shear deformation is loaded on a damping layer by a press operation and the layer is seperated from the steel sheet, the basic function of the damping layer is lost.

3 Ultrasonic Transmittance Measurement of Adhesion of Damping Layer

The measurement of adhesion of damping layer by an ultrasonic transmittance method is shown in Fig. 7. Since the condition of adhesion can be checked by this method without destroying a product, it becomes much easier to check for a damage of damping layer caused by a press operation as shown in the above the method can also be applied to an evaluation of laminated damping steel sheet in the development stage as well as to an conditioning made in a production line.

The gain of ultrasonic transmittance indication should be adjusted to a full scale '10' on a sheet having a good adhesion before it is formed by a press machine. The evaluation criteria for a good adhesion should be scale 8 or above, no good adhesion scale 2 or below and uncertain and unreliable adhesion scale between 2 to 8.

Those criteria are compared with T-Peel strength in Fig. 8 (2). Though they do not match perfectly, the correlation between two systems verifies the sufficient practicability of such evaluation.

Fig. 9 shows the result of ultrasonic transmittance test performed by the method shown in Fig. 7 on the adhesion of damping layer of an engine oil pan as an example of laminated damping steel sheet with a major press formation. It indicates that separations of damping layer took place locally. The evaluation was verified by a T-Peel strength test which was performed later on the same specimen. The result, meanwhile, indicates that an application in a deep drawn oil pan gives a laminated damping steel sheet a very harsh processing.

Shear deformation caused on the damping layer is large on the side wall as shown in Fig. 5 and, therefore, this area is more susceptible to an incomplete adhesion which means separation. The possibility of separation is reduced on the right wall because of a local protrusion provided on it. Some separation is noted on the bottom surface due to nonsymmetry of the left and the right as well as the front and the rear walls. It is a very complicated phenomenon.

Fig. 10 shows the result of vibration test performed on pieces of laminated damping steel sheet derived from the side and the bottom walls of oil pan as shown in Fig. 9. It is indicated that the piece retain good damping property from the bottom wall and no good one from the side wall. The evaluation, meanwhile, obtained by the ultrasonic transmittance test was found no good on the side wall and good for the bottom. So, reduction of damping characteristic due to partial separations of damping layer can be seen in the graph.

4 Structure Damping in Complex Structure and η Value Required for Damping Treatment

Fig.11 shows an example of structure damping measured on a reciprocating engine. The basic structure of an engine is constituted by cast iron cylinder block, cylinder head, etc. and η value of those component materials is approximately 0.001. According to Fig.11, η value for engine structure is between 0.01 and 0.04, about 10 times as large as η of materials.

This is due to the structure damping, a combination of friction damping produced by each bolt joint face, etc. and oil damping produced by an oil film formed on the bearings of various rotating shafts. Larger η values, shown there while the engine is in a running condition, are realized by the damping effect of oil films formed on the bearings by the rotation of shafts.

For the purpose of an accomplishment of damping treatment for the reduction of vibration and noise on a very complicated structure as engine, a target η to be set is recommended to be larger than 0.1 by the past experiences because the effect of original structure damping is quite large.

5 η Value of Pressed Laminated Damping Steel Sheet Component and its Effect

Fig.12 shows the cantilever beam measurement method of loss factor η for a laminated damping steel sheet. A steel spacer is inserted between two steel sheets in lieu of a damping resin layer in the portion where the beam is fixed to the clamping block to accommodate an adaptability to boundary condition.

η of laminated damping steel sheet measured by the method shown in Fig.12 before it is formed by a press is shown in Fig.13. Nomogram and shift factor calculated by the data in Fig.13 are shown in Fig.14. Fig.15 shows the temperature and frequency characteristic of viscoelastic material itself.

In consideration of the structure damping in a bolted condition, the method of η measurement, on an oil pan made of laminated damping steel sheet and installed on an engine, is shown in Fig.16. The temperature of oil in the oil pan is constantly regulated to a certain level because the damping characteristic of laminated damping steel sheet is greatly influenced by the temperature. Fig.17 shows the result of test in Fig.16.

The solid line in Fig.17 is the damping characteristic derived from the calculation of viscoelastic data shown in Fig.15. The line indicates η which is the same as the one for the laminated damping steel sheet not processed by a press, obviously clear of mutual slip of steel sheets, and subjected to the same vibration mode. This sheet is a high temperature type which delivers the maximum η value at around 70 °C, a temperature at which an oil pan is usually kept while an engine is in operation. It has η value exceeding 0.1 in a wider range.

In comparison to this solid line, there is a substantial reduction of η value on a laminated damping steel sheet after it is formed into an oil pan. As shown in Fig.9, separation of damping layer takes place more often on the left side wall of oil pan. For this reason, the reduction of η on the left side wall becomes larger to an extent that it goes under 0.1, the value which is put up as the target for η by the past experiences. [4]

Fig.18 shows the effect of laminated damping steel sheet realized on sound power level at various points on an outer surface of oil pan while an engine is in operation. It is noted that a close correlation exists between this effect and the adhesion of damping layer shown in Fig.9 as well as η value shown in Fig.17.

Fig.19 shows sound pressure measured on the left side wall and the bottom of oil pan. The plots show that a noise reduction ranging from 1 to 2 dB(A) was accomplished on the left side wall and 2 to 3 dB(A) on the bottom. Both indicate that substantial damping was accomplished. Even though an accurate comparison was not made in this case, 60 % to 80 % sound power of the oil pan is normally supplied by the resonant peak of an outer panel which yields to a damping effectively. And, therefore, if a large η value is made available, much larger noise reduction will become feasible. [5]

6 Summary

From the above, it can be said that a laminated damping steel sheet before it undergoes a press forming operation will have a substantially large η value than those of general structured components but if a separation of damping layer from steel sheets are caused by the bending operation of press, there could be a large reduction of η value to an extent that sometimes it goes under the expected value though all the damping effect is not necessarily lost. For the compensation of such reduction, an increase of maximum permissible mutual slip , δ_{MAX}, of damping layer by material improvement, review of press operation conditions, increase of layer thickness, etc. are being studied, however, a modification in pressed form where the mutual slip can further be restrained should be explored, too. Increasing the thickness of damping layer is relatively simple method but it may create new problems in bolt loosening or press formability of steel sheet and, therefore, its application is rather limited . [6], [7] Under the circumstances, diversified studies in applied engineerings in the fields of materials, production engineering, designs, etc. as mentioned above should be carried out for an accomplishment of noise reduction in a deep drawn product such as an engine oil pan as it was discussed in this paper.

Reference

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(2) H.Okamura et al.;Application of Damping Steel Sheet to Oil Pan, Journal of SAE of Japan, Vol.41 No.7 (1987),p729~737.(in Japanese)

(3) M.Yoshida; Press Formability of Vibration-Damping Sheets, Proceedings of the 37th Japanese Joint Conference for the Technology of Plasticity, No.37 (1986-11),p7~12 (in Japanese)

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(5) S.Wada,H.Okamura et al.;Transient Response of Engine Structures by Impulse Excitation, Mitsubishi Heavy Industry Technical Review, Vol.20 No.5 (1983)

(6) Y.Watanabe et al.;Development of Vibration-Damping Sheets, SAE Paper, No. No.850325 (1985)

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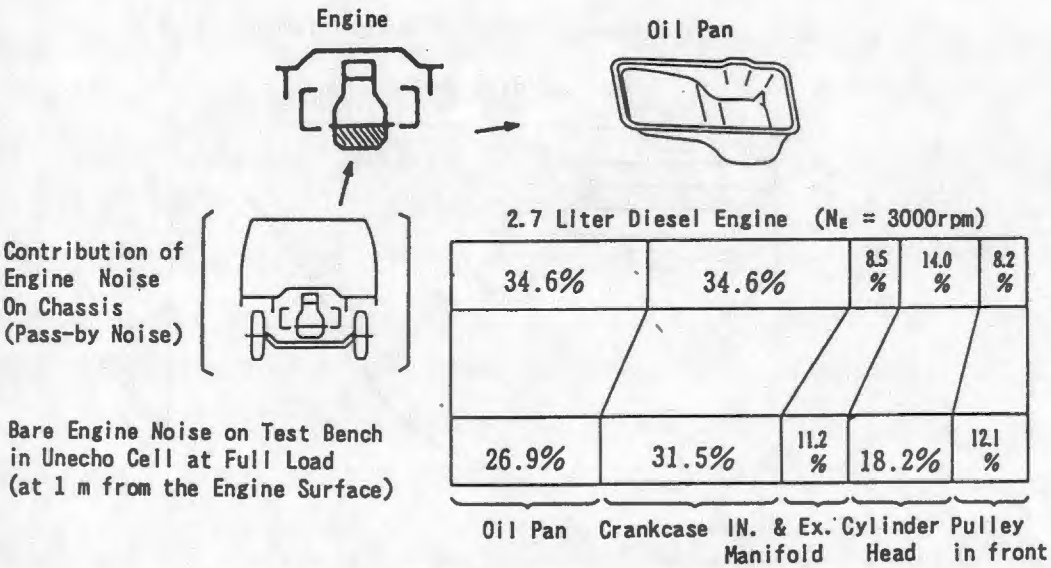


Fig. 1 Noise Contribution Ratio of Various Engine Components

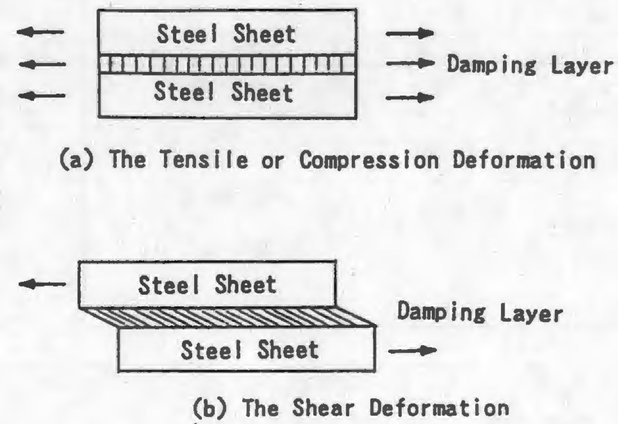


Fig. 2 Deformations of Damping Layer in a Press Operation

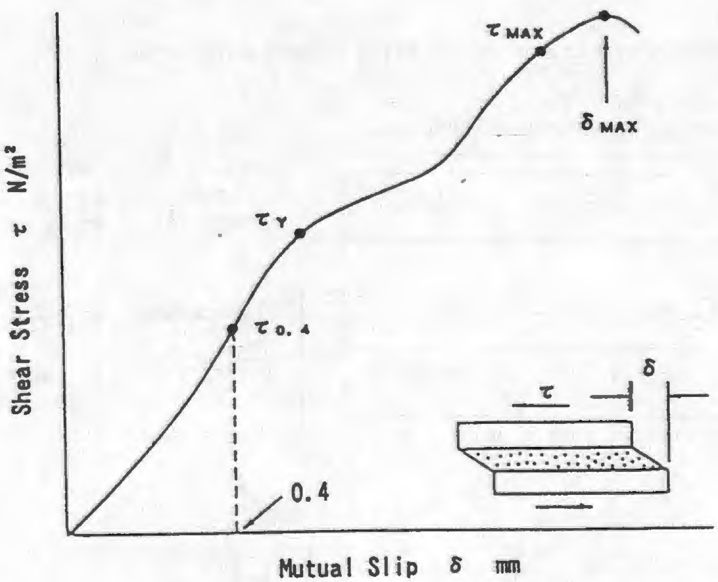


Fig. 3 Schematic Curve of Shear Stress vs Mutual Slip

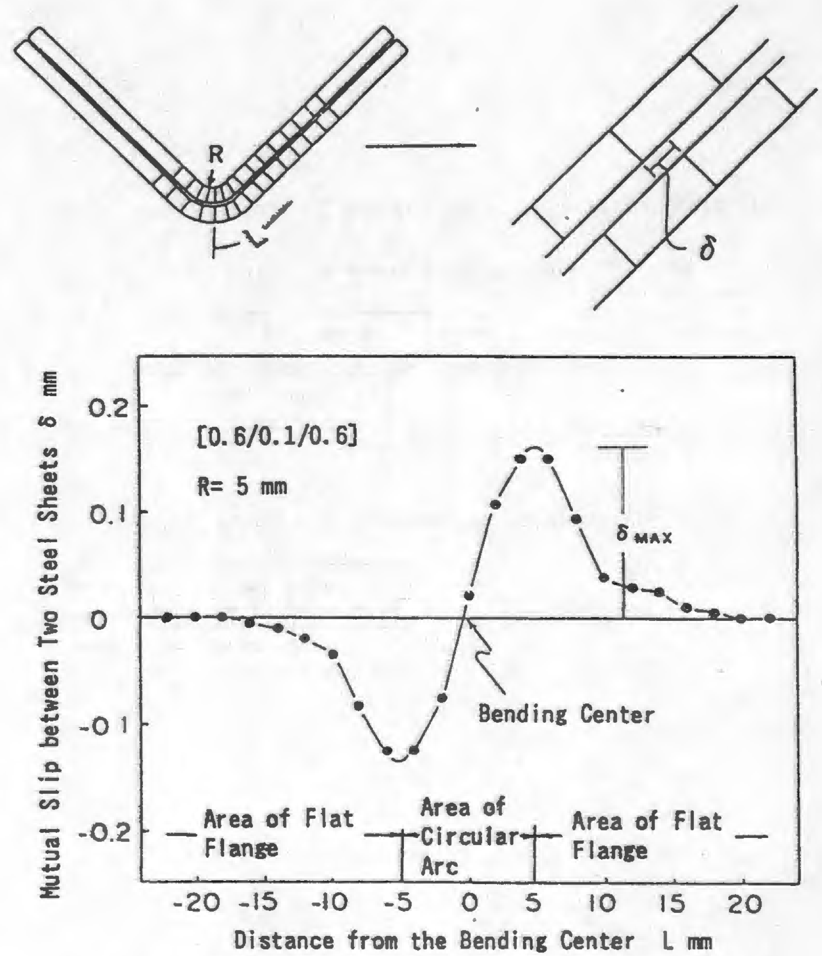
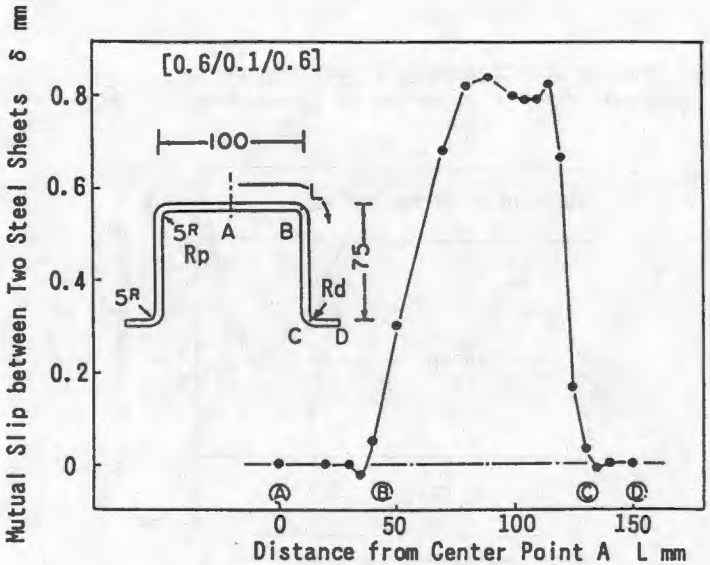
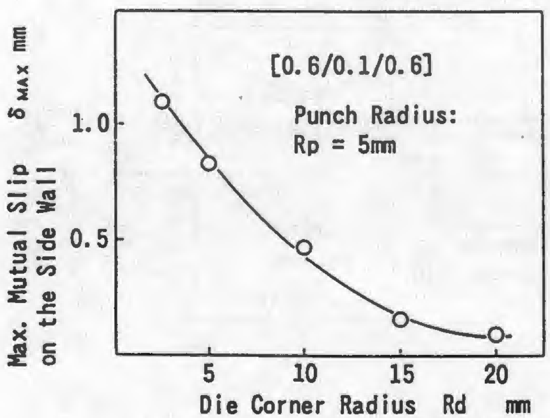


Fig. 4 Mutual Slip between Two Steel Sheets of Laminated Damping Steel Sheet after V-Press Bending



(a) Distribution of Mutual Slip



(b) Influence on Die Corner Radius

Fig. 5 Mutual Slip between Two Steel Sheets of Laminated Damping Steel Sheets after Channel Type Drawing

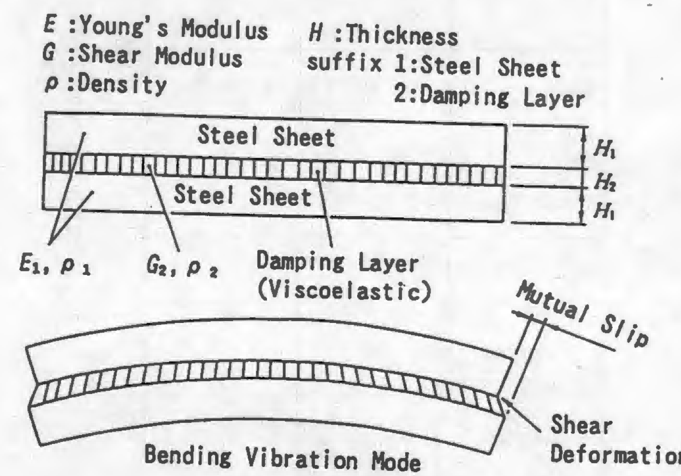


Fig. 6 Laminated Damping Steel Sheet

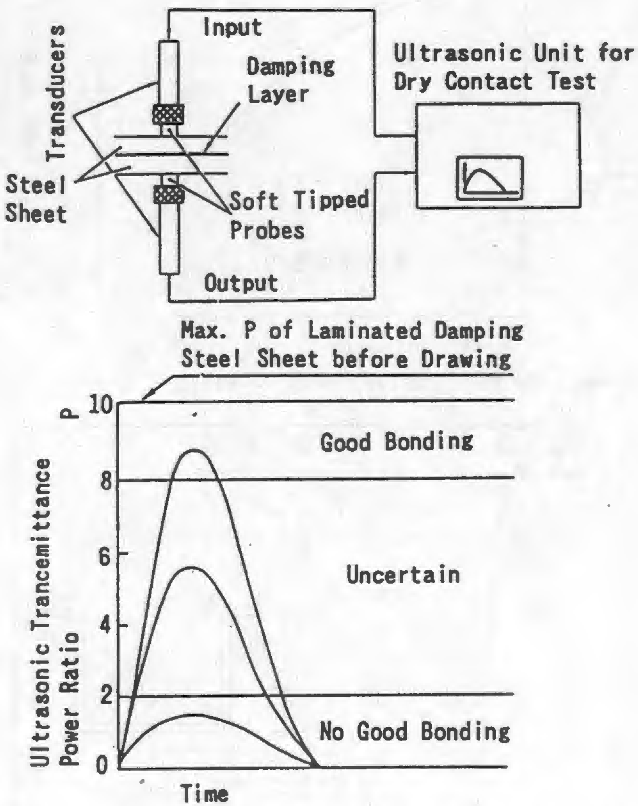


Fig. 7 Measurement of Adhesion of Damping Layer by an Ultrasonic Transmittance Method

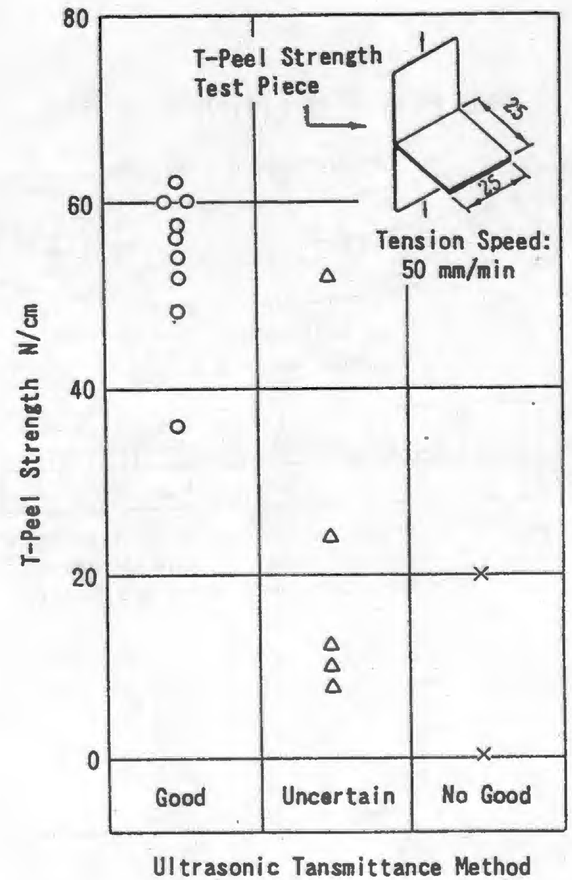


Fig. 8 Correlation between Ultrasonic Trancemittance Method and T-Peel Strenghth Test Method about the Adhesion of Damping Layer

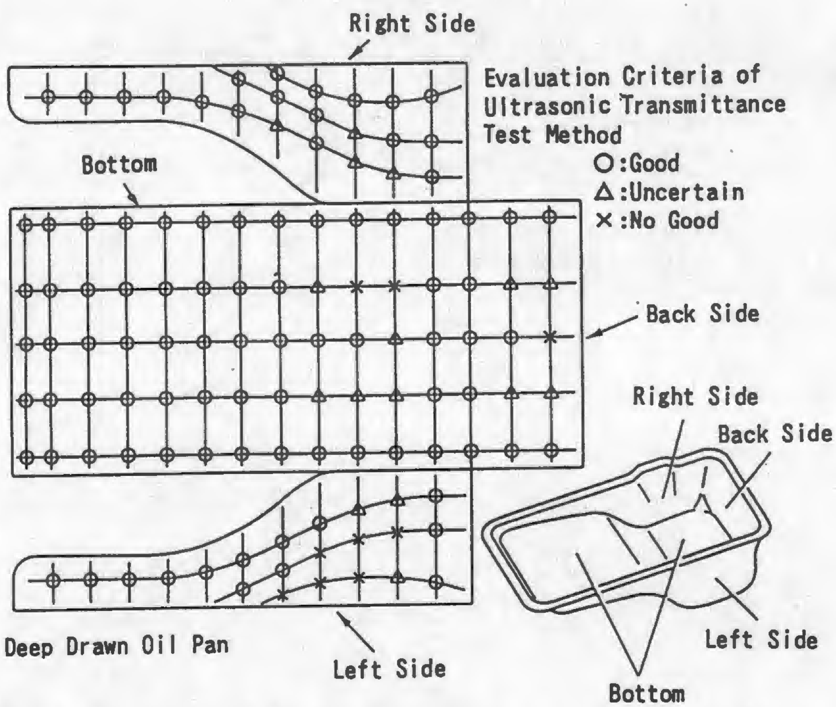
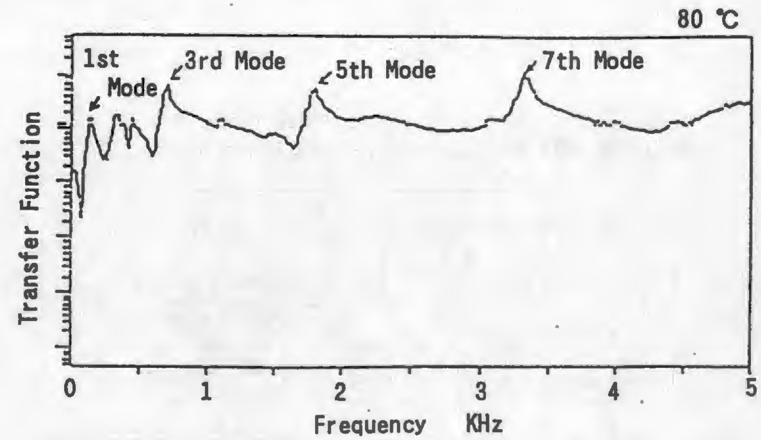
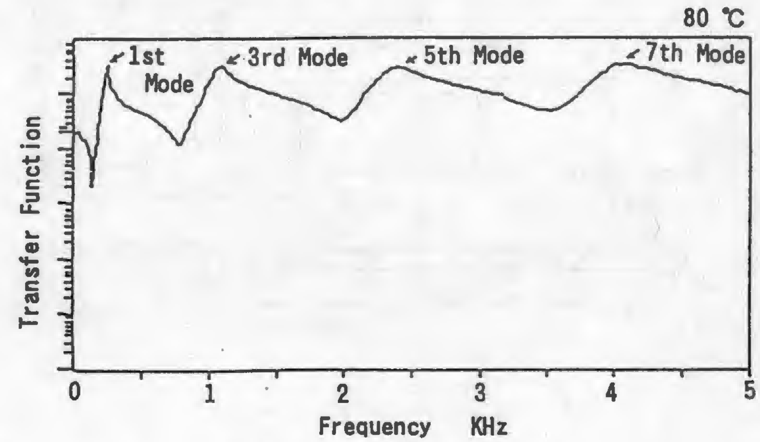


Fig. 9 The Result of Ultrasonic Transmittance Test on the Adhesion of Damping Layer of an Engine Oil Pan



(b) Piece from the Side Wall



(a) Piece from the Bottom Wall

Fig. 10 Loss Factor of Laminated Damping Steel Sheet Test Piece Derived from the Wall of Oil Pan

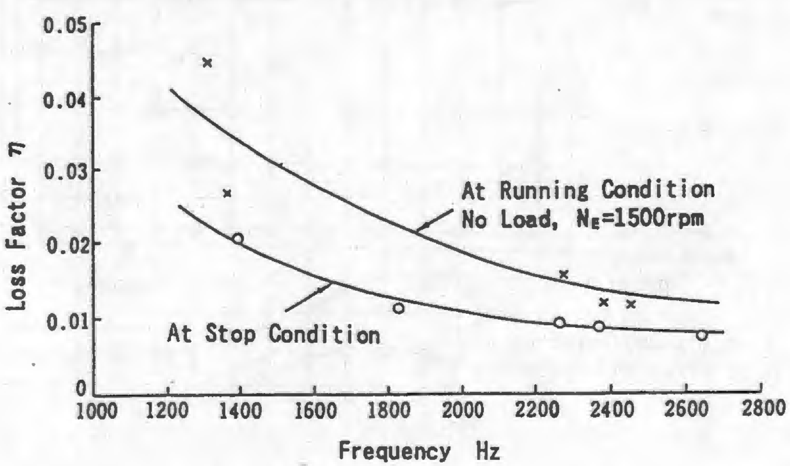


Fig. 11 Structure Damping of Reciprocating Engine

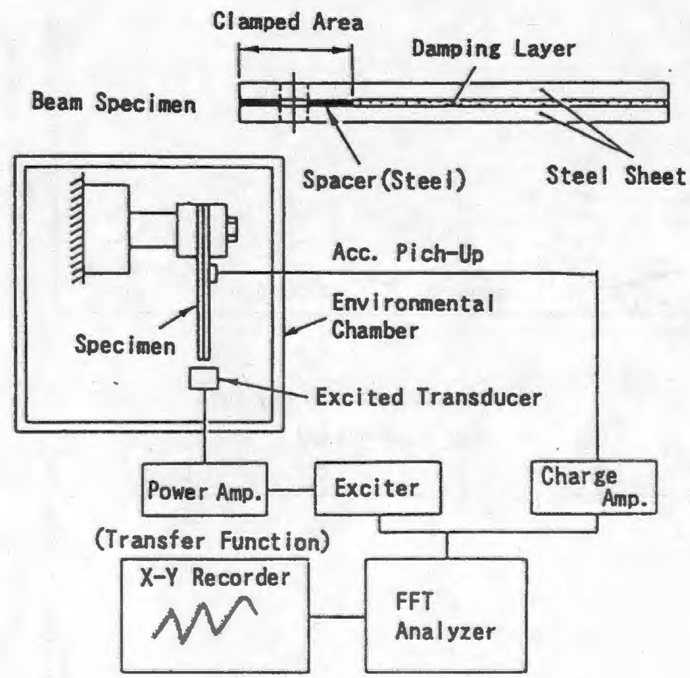


Fig. 12 Measurement Method of η Value for Cantilever Test Beam Piece

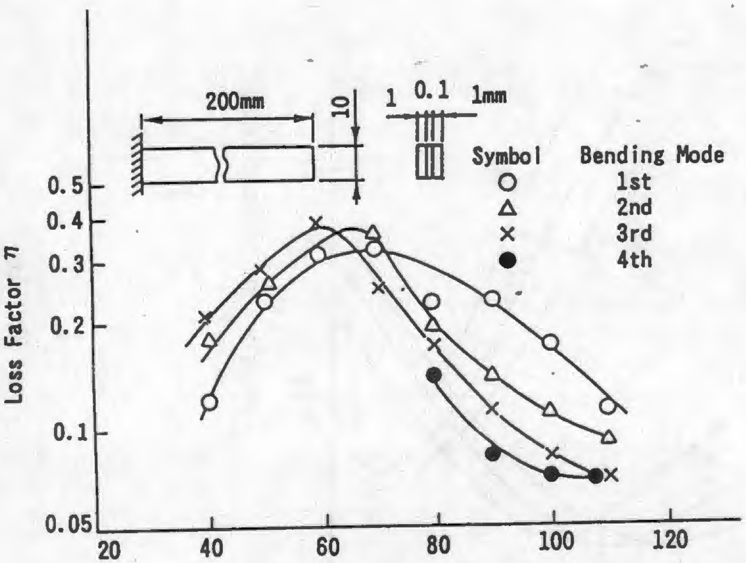


Fig. 13 Damping Property of Laminated Damping Steel Sheet Cantilever Test Beam Piece

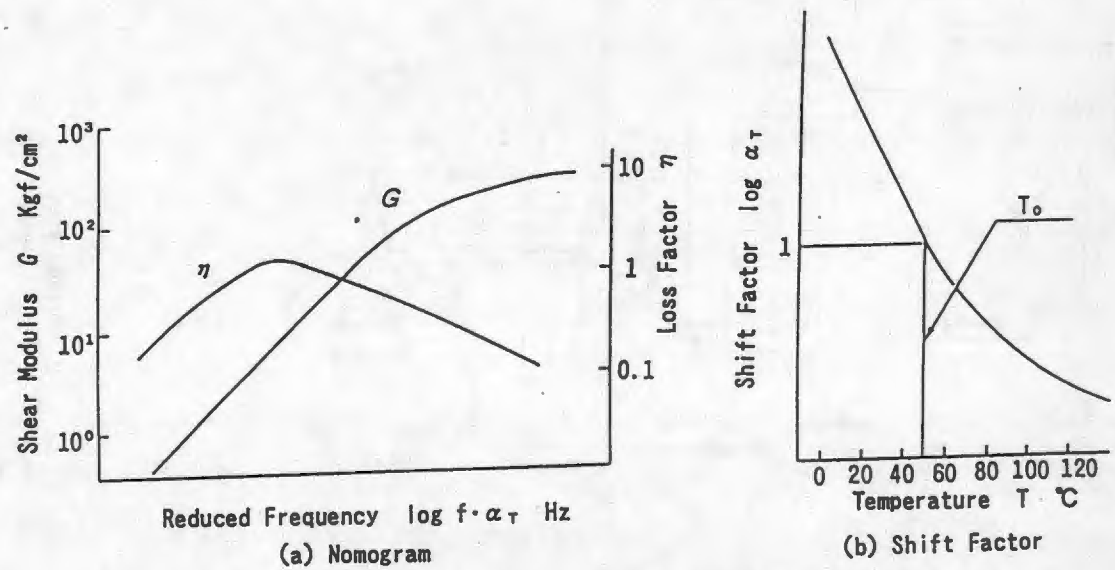


Fig. 14 Damping Characteristic of Viscoelastic Material (Damping Layer of Laminated Sheet)

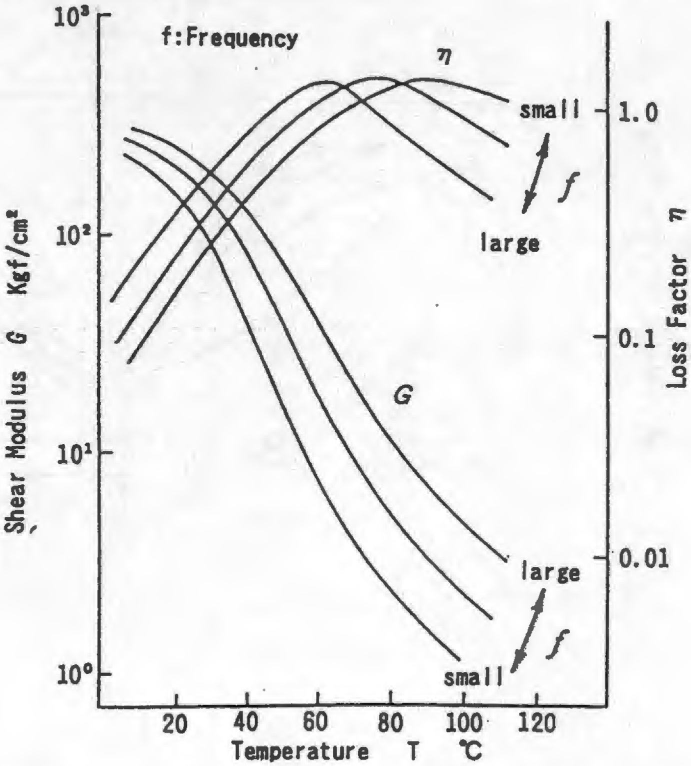


Fig. 15 Temperature and Frequency Characteristic of Viscoelastic Material (Damping Layer of Laminated Sheet)

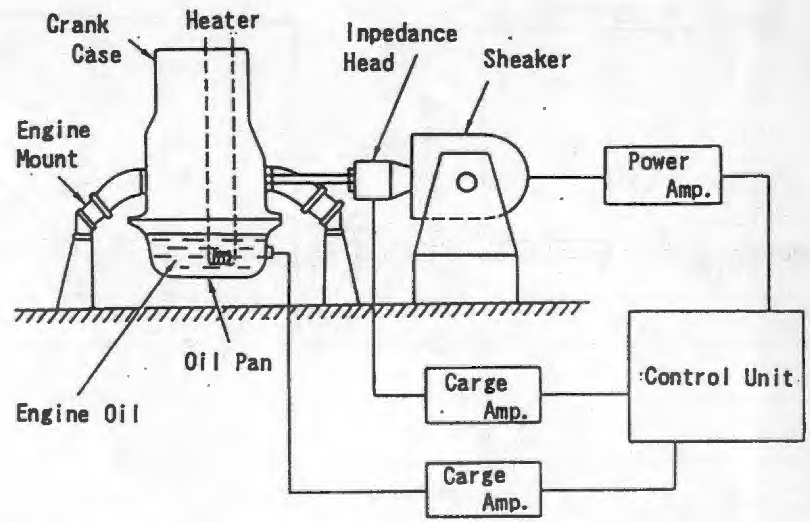


Fig. 16 Measurement Method of η Value for Oil Pan

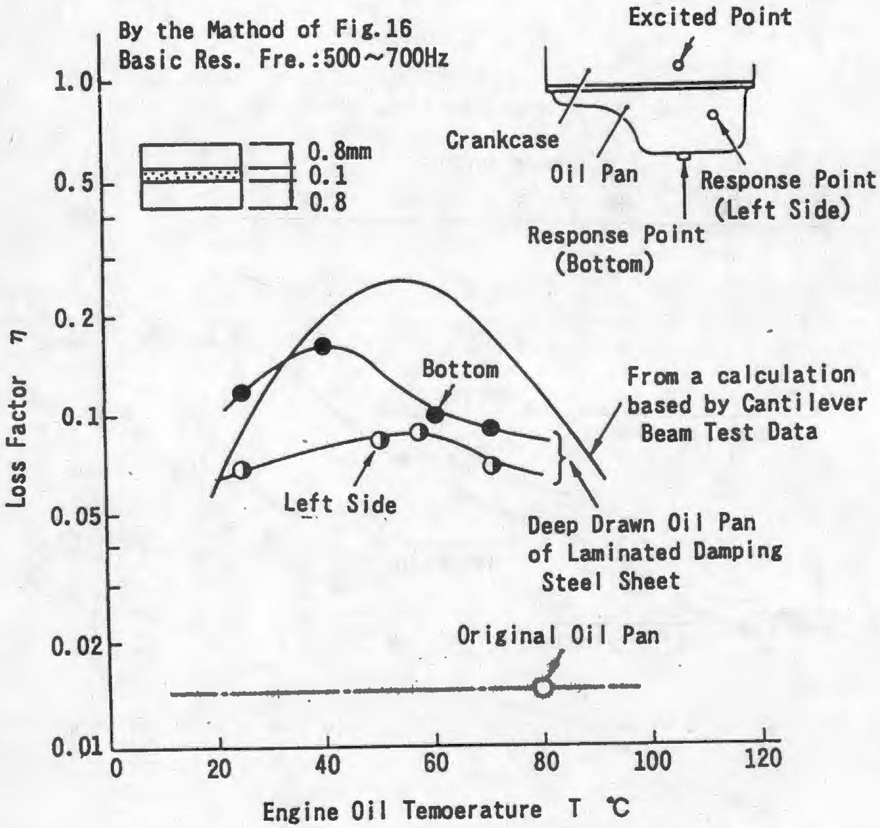


Fig. 17 η Value of Laminated Damping Steel Sheet Oil Pan

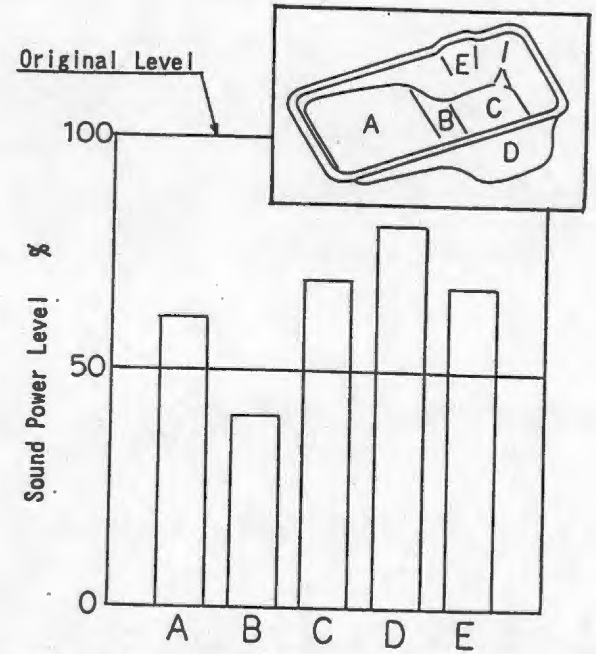


Fig. 18 Noise Reduction Effect on Sound Power Level of the Outer Surfaces of Laminated Damping Steel Sheet Oil Pan

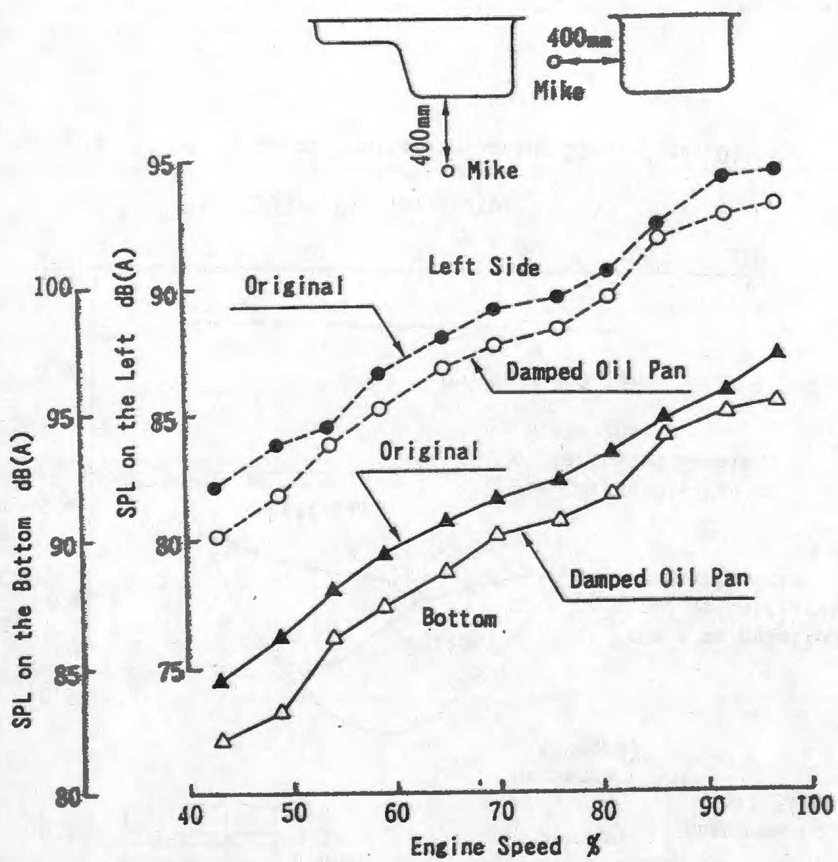


Fig. 19 Sound Pressure Level of Oil Pan