

Establishment of Analysis Method for Pulse Feeling of Four-stroke, V-twin Engine, American-type Motorcycles

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ABSTRACT

Pulse feeling is an important factor of ride comfort for V-twin engine, American-type motorcycles. Depending on sensory evaluation, the pulse feeling varies widely among estimators. Therefore, it takes a large amount of time to determine specifications. To solve this problem, a quantitative evaluation method was developed. In the development process, sensory evaluation testing using Japanese and American riders was conducted to verify how they feel the pulse. There was no significant difference between both sets of riders. Both sets of riders felt that seat vibration made the largest contribution to the pulse feeling. In order to quantify the seat vibration pulse, a pulse intensity indicator was added to the previous sensory vibration indicator. Furthermore, time domain response analysis was applied to a complete motorcycle analysis model. The output showed good correlation with the actual data. The pulse feeling indicator was obtained from the analysis results. Consequently, the established method has allowed early prediction of the pulse intensity at the design stage.

1. Introduction

Pulse feeling is a performance characteristic of American-type motorcycles. It contributes to the rider's comfort and to his/her impression of the ride. However, this evaluation is a sensory evaluation of the actual ride, and there is large variation in judgment among in-house evaluation experts. Additionally, a large amount of time is required to determine specifications using a trial and error approach. Evaluations before and after countermeasures cannot be quantified. Therefore, an index to quantitatively evaluate pulse feeling at the development stage was desired. In this research project,

sensory evaluation tests were conducted using Japanese and American riders. The purpose was to clarify differences in how pulse is perceived, and to clarify the component factors of pulse. Sensory evaluations were carried out with the test subjects seated on a vibration generator. The aim was to determine body sensory characteristics related to pulse, and to create a quantitative evaluation index. Furthermore, in order to establish a method for prediction at the design stage, body, engine and drivetrain models were created for the purpose of conducting time domain response analysis. This paper reports on the correlation to the actual measured data, and on development tools.

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2. Creating a Pulse Feeling Index

2.1. Pulse Feeling Component Factors

When quantifying pulse intensity, it is first necessary to clarify characteristics that people feel as pulse. Japanese and American subjects were surveyed to determine how they feel the pulse. Riding on a number of different types of American-type motorcycles, the subjects were asked to answer questions concerning where pulse feeling originates and how each location contributes to the overall feeling. Figure 1 shows the results with two American-type motorcycles. It is clear in Fig. 1 that both Japanese and American riders agree that the greatest pulse feeling comes from seat vibration.

Additionally, along with this survey, another survey was conducted. The second survey was related to how they want to feel pulse feeling. The results in Fig. 2 clearly show that both Japanese and American riders said that seat vibration was desired as pulse feeling.

For both Japanese and American riders, seat vibration was the major element contributing to pulse feeling. It was clear that this was desirable. Therefore, it was decided to quantify pulse intensity using seat vibration.

Here, if sensations concerning pulse intensity are different between Japanese and American riders, it is necessary to carry out tests for each country. In order to confirm whether or not there are differences, a survey was conducted to determine the level of intensity at which pulse feeling is felt. The Japanese and American riders assigned scores to the level of pulse feeling intensity when driving the same motorcycle at the same speed under the same conditions. The results are shown in Fig. 3. It was determined that there is no significant difference between Japanese and American riders, in the way in which pulse intensity is felt. Accordingly, with Japanese riders as the test subjects, an attempt was made to quantify pulse intensity using seat vibration.

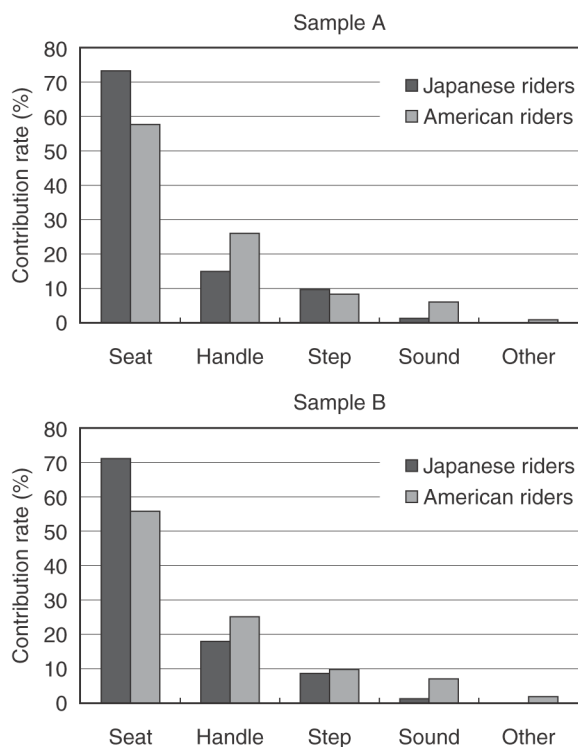


Fig. 1 Contribution to pulse feeling

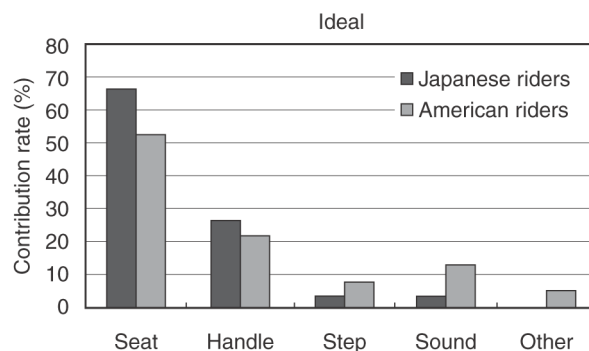


Fig. 2 Ideal contribution to pulse feeling

2.2. Process of Creating Index

2.2.1. Quantification of seat vibration intensity

Pulse intensity quantification was carried out using seat vibration. A previous in-house method was used in quantifying seat vibration intensity.

The following is an explanation of seat vibration intensity quantification. Seat vibration intensity is the level of intensity of seat vibration that is felt. In the field of acoustics, the level of sound felt by people is defined as "loudness", in contrast to the physical property of sound pressure. In the same way, the intensity of vibration felt by people is defined as the "Vibration Intensity Index" using the physical property of vibration acceleration.

The values of sensation of vibration intensity are known to differ according to frequency and direction. As a method for correcting values of sensation of vibration acceleration, ISO2631-1 defines the weighting curve according to whole-body vibration frequency and direction. This is similar to A-weighting in the field of acoustics⁽¹⁾. Figure 4 shows the whole-body vibration weighting curve at the seated position according to ISO definition.

However, experiments have shown the vibration acceleration with this ISO weighting added uniformly to be different from the intensity of seat vibration sensation. It is believed that a major cause is that the frequency weighting is different according to vibration acceleration⁽²⁾. It was decided to create a curved surface that can define seat vibration intensity according to frequency and vibration acceleration in each direction (back/forth, right/left and up/down). The vibrations created by a vibration generator were applied to the human body in a riding position on the motorcycle. The sensory evaluation tests⁽³⁾ were repeated. Sensory evaluations were carried out for the following four items.

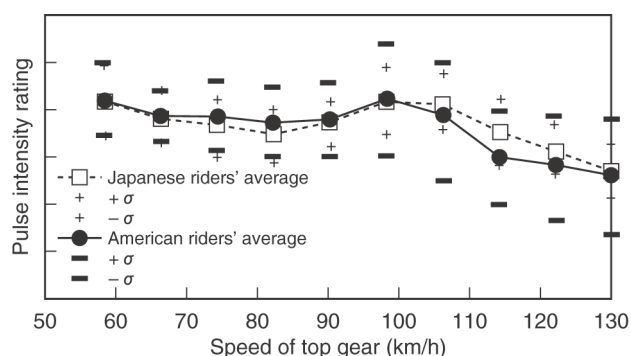


Fig. 3 Difference in pulse feeling rating

(1) Threshold investigation

An investigation of vibration acceleration threshold values, according to each direction, frequency.

(2) Investigation of equal sensation acceleration cause by vibration frequency

Using the paired comparison method, an investigation was made of vibration acceleration that was felt as the same vibration intensity, in the same direction at various frequencies.

(3) Investigation of equal sensation acceleration caused by vibration direction

Using the paired comparison method, an investigation was made of vibration acceleration that was felt as the same vibration intensity, in different directions but at the same frequency.

(4) Investigation of subjective feeling

Investigation of the relationship between sensory vibration intensity and vibration acceleration

As a result of these investigations, the curved surface of up and down direction (Z-axis) obtained are shown in Fig. 5.

Using these curves, it was possible to evaluate seat vibration intensity by measuring vibration acceleration for

three axes and carrying out frequency analysis. Figure 6 shows the concept diagram outlining the calculation of the “Vibration Intensity Index” from the results of the frequency analysis of vibration acceleration measured on an actual motorcycle. By correcting vibration accelerations according to the sensory value curves for each direction, it is possible to combine 3 directions and obtain a single “vibration intensity value”.

2.2.2. Difference between vibration and pulse feeling

Using the method described in Section 2.2.1, it has become possible to quantify a sensory level of vibration. Figure 7 shows the changes in “Vibration Intensity Index” due to certain American-type motorcycle engine speeds. Here, particularly in the high rpm range, the “Vibration Intensity Index” is large. The issue arises that this is not

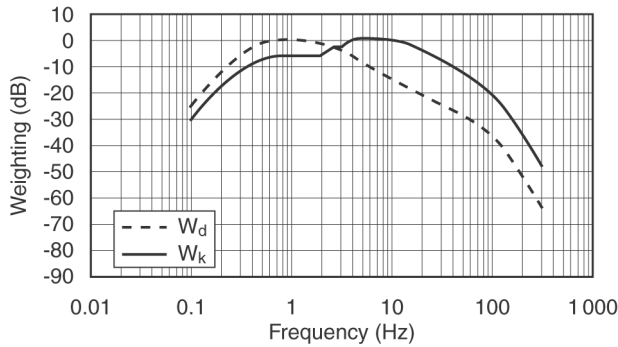


Fig. 4 Frequency weighting curves

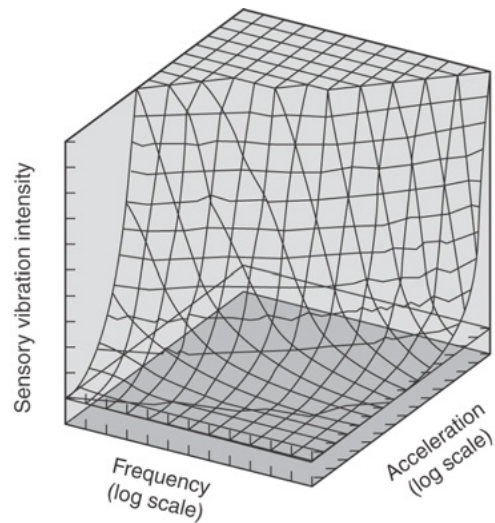


Fig. 5 Sensory vibration intensity curved surface for Z-axis

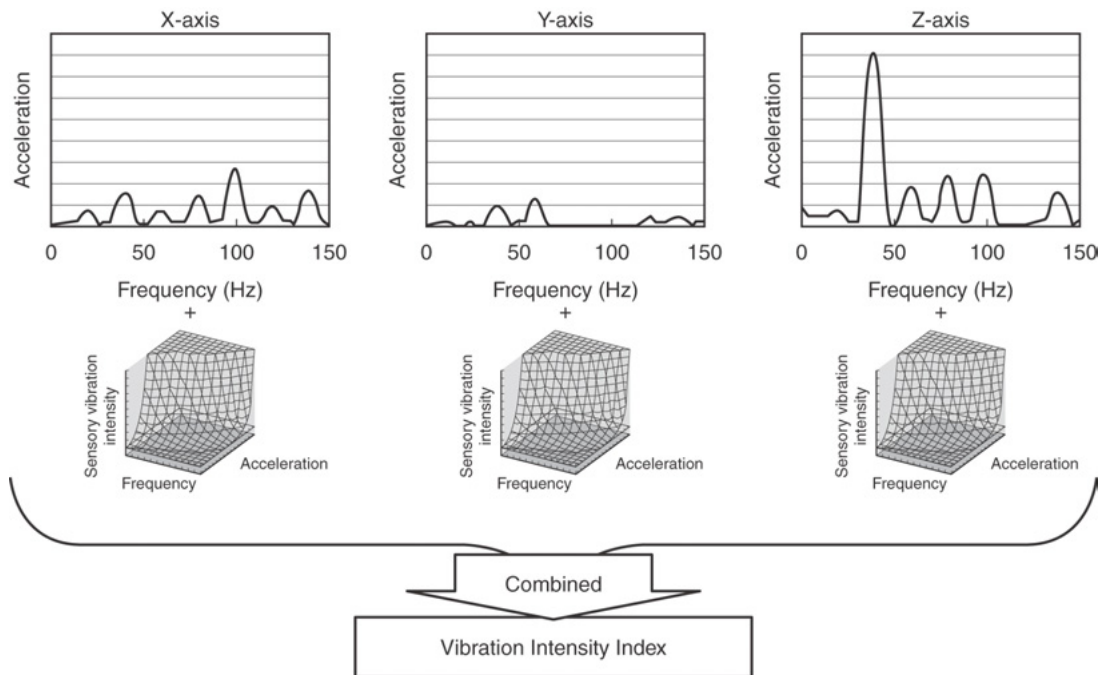


Fig. 6 Notion of “Vibration Annoyance Index” calculation method

perceived as pulse feeling. When an interview was made, it was determined that pulse feeling was an evaluation related to beating vibration. High frequency vibration was not evaluated as pulse feeling. Additionally, from the results of the tests using vibration generators, the question of whether or not something is perceived as pulse feeling does not depend on the level of the vibration acceleration, but on the frequency (that is to say, on engine speed in an actual motorcycle).

Therefore, a new index was developed that differentiates between vibration and pulse feeling. An investigation related to the level of engine speed up to which vibration is taken as pulse feeling was completed. Vibrations produced by several V-type 2-cylinder engines, common on American-type motorcycles, were selected at each engine speed and applied to the test subjects using a vibration generator. The results are shown in Fig. 8.

As clearly shown in Fig. 8, with a V-type 2-cylinder engine, when 4 000 r/min is exceeded, almost none of the test subjects perceived vibration as pulse feeling. The reciprocal number of the cumulative frequency of replies of perception as pulse feeling was adopted as the representative pulse feeling filter for V-type 2-cylinder engines. This filter was applied to the "Vibration Intensity Index", and with the high frequency vibration excluded, a pulse intensity "Pulse Beat Index" was created.

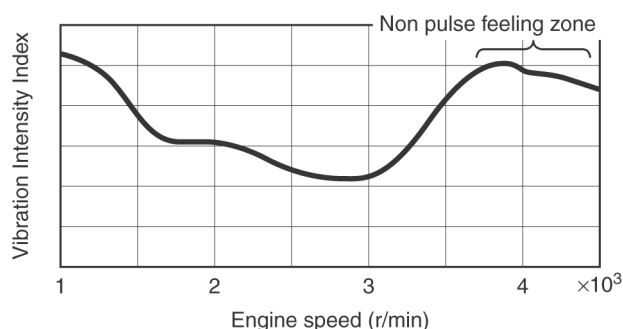


Fig. 7 "Vibration Intensity Index" alteration

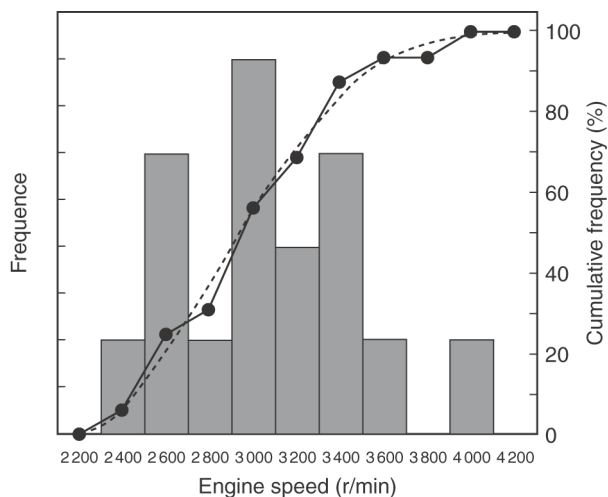


Fig. 8 Consciousness of pulse feeling

2.2.3. Verification of the index

Figures 9 and 10 show the evaluation scores according to the "Pulse Beat Index" calculated from the measured acceleration, and the sensory evaluations. The calculated pulse feeling "Pulse Beat Index" show good conformity with the sensory evaluation scores, including motorcycle model differences (Motorcycle A/ Motorcycle B) and different driving conditions (full load, partial load). This confirms the effectiveness of the index.

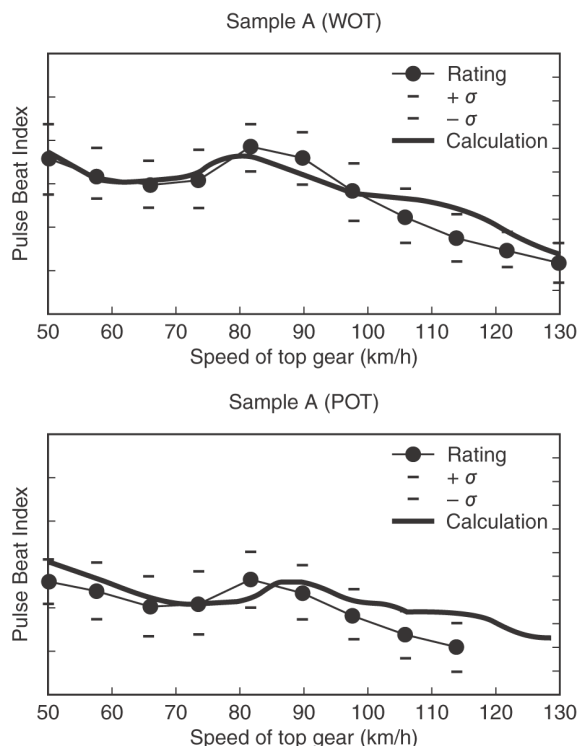


Fig. 9 "Pulse Beat Index" of sample A

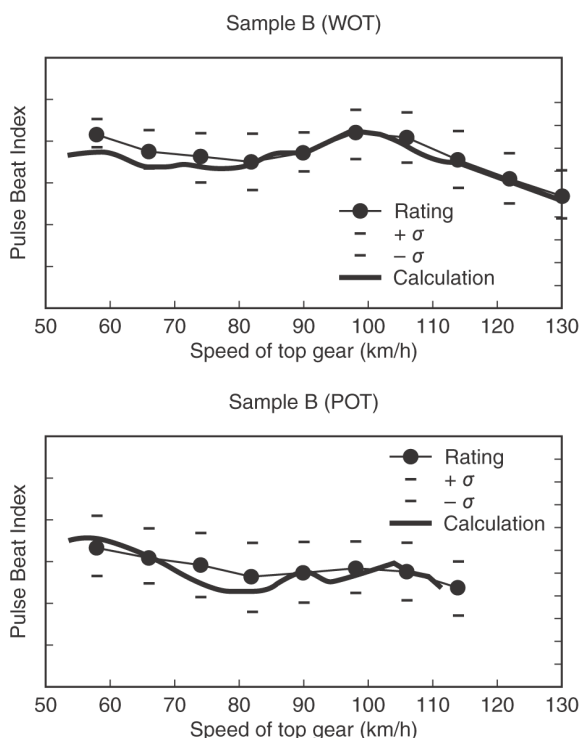


Fig. 10 "Pulse Beat Index" of sample B

3. Application of Time Domain Response Analysis

3.1. Overview of Analysis

A method of predicting vibration from the engine caused by the inertia force of reciprocating parts was established, and has become an effective development tool⁽⁴⁾. However, related to pulse, torque fluctuation components due to combustion are important. Therefore, it is not possible to reproduce this using conventional frequency response analysis, and it cannot be predicted at the design stage. Using mechanical analysis software (ADAMS), time domain response analysis⁽⁵⁾ was carried out by integrating the Craig-Bampton model determined from the results of eigen value analysis and static rigidity analysis with the engine and drivetrain model. The correlation with the test data was then verified. Combustion pressure data determined from testing was used as input.

3.2. Analysis Procedure

Figure 11 shows the procedure for time domain response analysis.

3.3. Results of Analysis

3.3.1. Results of eigen value analysis model and frequency response calculations

In order to carry out time domain response analysis, a precise FE model of a completed motorcycle is necessary. Figure 12 shows the analysis model, and Fig. 13 gives the frequency response calculations. Figure 13 shows the results of frequency response calculations in the case when actual engine inertia force of reciprocating parts is added to the eigen value analysis results. The frequency analysis results are from an actual motorcycle. For modeling accuracy verification, a comparison in the motorcycle driving state is best, and as a time domain response analysis model, it is judged sufficiently accurate.



Fig. 12 Complete motorcycle FE model

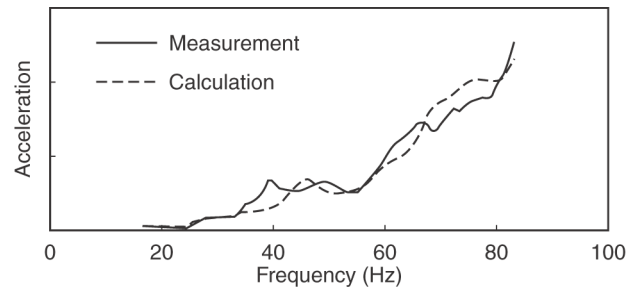


Fig. 13 Acceleration responses of complete motorcycle

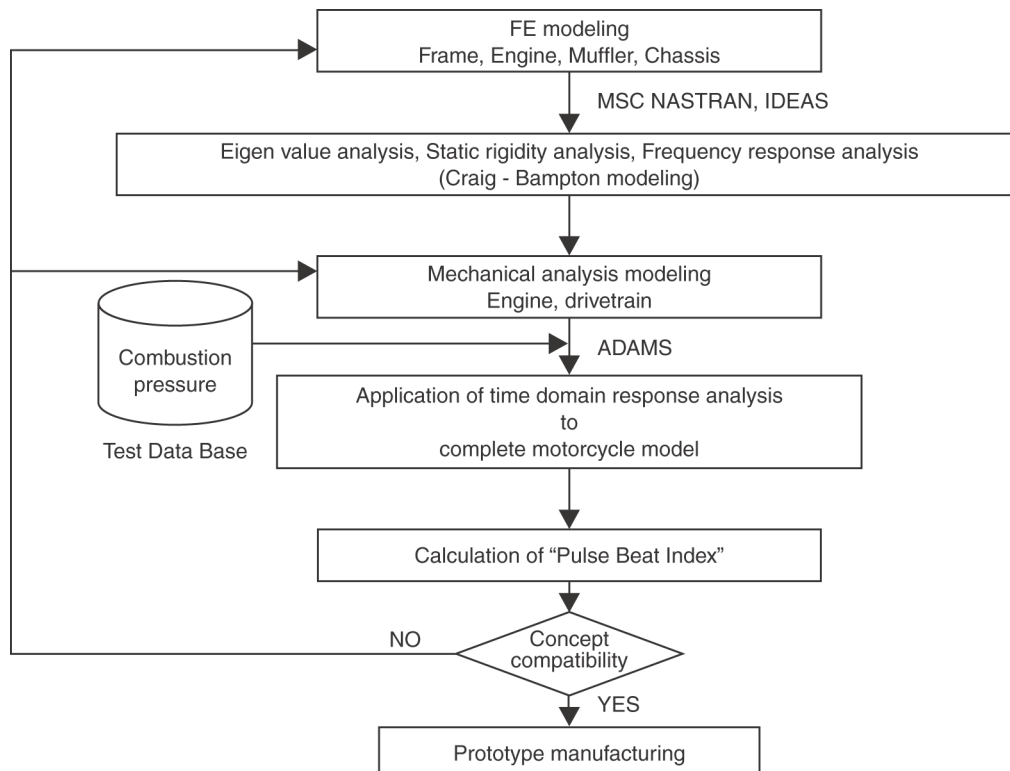


Fig. 11 Flowchart of time domain response analysis system

3.3.2. Time domain response analysis model

A mechanical analysis model was created, for the engine and drivetrain. Concerning the drive system, modeling was carried out of each detailed part, such as damper, drive shaft, etc. These models were combined with the Craig-Bampton model determined from the results of the eigen value and static rigidity analysis obtained in Section 3.3.1, creating a completed motorcycle model. Figure 14 shows the engine and drivetrain model, while Fig. 15 shows the time domain response analysis of the complete motorcycle.



Fig. 14 Engine drivetrain mode

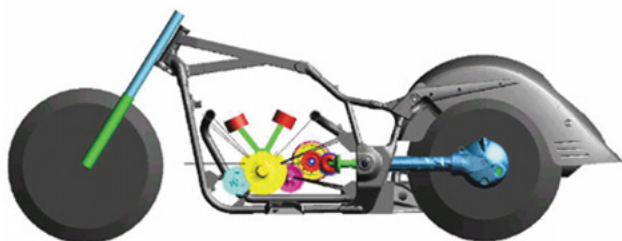


Fig. 15 Complete motorcycle time domain analysis model

3.3.3. Results of time domain response analysis

Figure 16 shows the input data (motorcycle combustion pressure), and Figs. 17 and 18 show the results of time domain response analysis and of frequency analysis. As shown in Figs. 17 and 18, there is a favorable correlation between time domain measurement data and calculation results. The same is true of frequency analysis results. From these results, "Pulse Beat Index" is determined, and it is possible to judge pulse intensity. This is effective as a pulse analysis tool. Figure 19 shows the changes in development procedure.

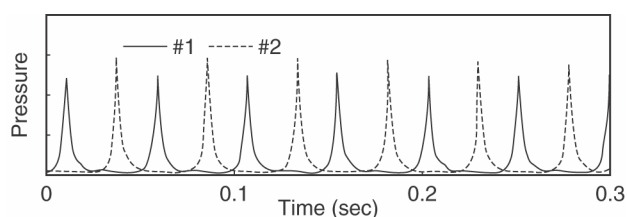


Fig. 16 Input data (Combustion pressure)

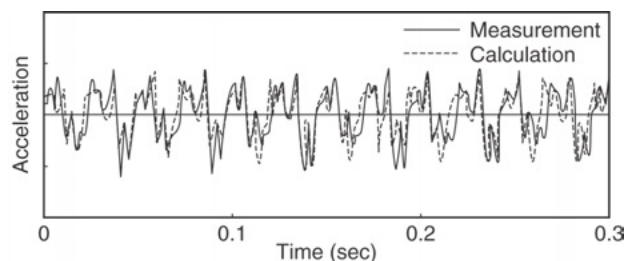


Fig. 17 Result of time domain response analysis

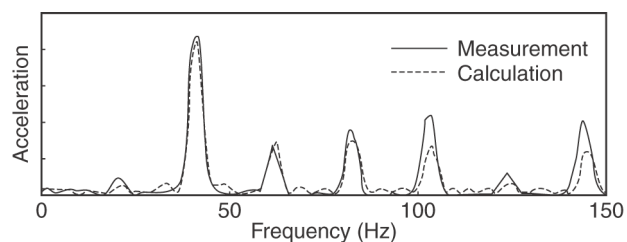


Fig. 18 Result of frequency response analysis

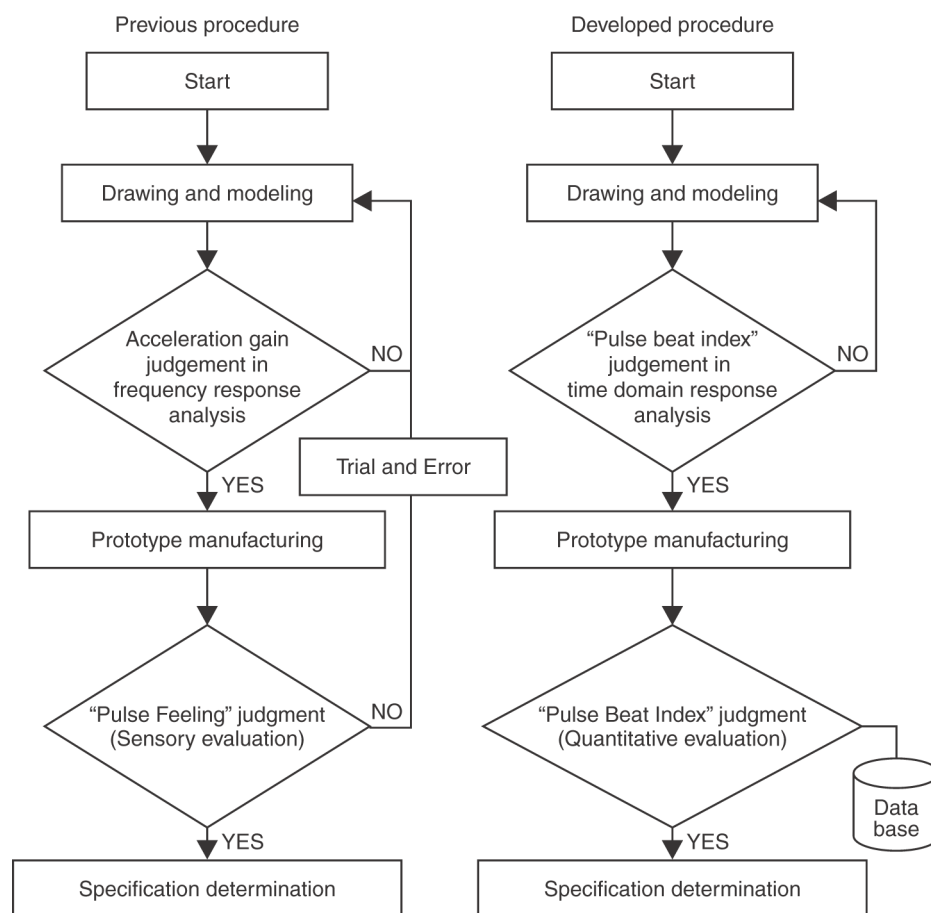


Fig. 19 Flowchart of development procedure

4. Conclusion

- (1) Through the development of the "Pulse Beat Index", pulse feeling, which has conventionally been a qualitative evaluation, has now become a quantitative evaluation. This makes it easier to judge test motorcycles and confirm the effectiveness of countermeasures.
- (2) Through time domain response analysis of the complete motorcycle, clarification was made of each part's contribution to pulse. It is now possible to predict "Pulse Beat Index" at the design stage. It was also possible to reduce test time and the time for determining specifications.

The focus of this project was quantification of pulse intensity, but there are some cases where "pulse quality" is an issue in the evaluation of pulse feeling. In the future, research will be carried out into how people perceive "pulse quality".

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