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ANALYSIS OF THE POSSIBILITY OF USING THE PHASE ANGLE IN THE EUSAMA METHOD AS AN ADDITIONAL DIAGNOSTIC PARAMETER IN THE ASSESSMENT OF THE TECHNICAL CONDITION OF THE VEHICLE SUSPENSION SYSTEM

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Summary

Vehicle suspension system diagnostics is essential to both operation and maintenance of automotive vehicles. Diagnostic methods should provide signals that in-service defects have occurred as early as possible and make it possible to identify such defects in an unambiguous manner. Among the most popular oscillatory methods used to examine the technical condition of suspension systems, the EUSAMA method, developed by the European Shock Absorbers Manufacturers Association, has enjoyed particularly wide application, and it consists in establishing the ratio between the minimum value of the wheel adhesion force within the band of resonance of unsprung masses and the static wheel load value, expressed in per cent. Technical condition classification is based on comparing the values of what is commonly referred to as the EUSAMA coefficient (percentage ratio of a minimum wheel load force to a tangential vehicle wheel load on a test stand plate) for two wheels of a single axle. Such a test stand typically features only a load force sensor integrated with the test plate. The modification proposed by the authors involves installing an additional test plate displacement sensor at the test stand. When performed simultaneously, measurements of the load force affecting the plate and of its displacement make it possible to determine the phase angle between the relevant signals and to analyse the possibility of using the phase angle as an additional source of information about the technical condition of the vehicle suspension system.

Keywords: EUSAMA method, shock absorbers, damping characteristics, phase angle

1. INTRODUCTION

The operation of a vehicle entails progressing wear and tear of its components, consequently leading to gradual deterioration of its technical condition. With regard to systems such as brakes, suspension, chassis, etc., the deterioration of technical condition is imperceptible to drivers over a relatively long period of use. In most cases, users fail to notice this deterioration phenomenon as a consequence of wear and tear processes.

Diagnostics of the technical condition of suspension systems in the course of the operation and maintenance of automotive vehicles is extremely important. The diagnostic methods in use should enable unambiguous identification and signal the occurrence of in-service defects as early as possible. Organoleptic diagnostic testing of suspension systems involves visual inspection of the technical condition of individual components as well as of the connections between them, the purpose of which is to identify cracks and permanent deformations of the suspension system components, and to verify that these connections are reliable. Preliminary visual inspection also provides information on the condition of elastic elements and on the mechanical damage suffered by shock absorbers, provided that it is visible. It is doubtless that the technical condition of shock absorbers affects the vehicle behaviour and the safety of the vehicle use [1, 2, 5, 6, 8, 19-21, 23, 27-29].

Defective shock absorbers increase braking distances and – with the ABS or ESP systems on board – can prevent these systems from functioning properly, particularly under unfavourable road conditions (uneven road surface, curved track, braking, and acceleration). Two kinds of criteria are applied to assess technical condition: the threshold value criterion for a given diagnostic parameter, e.g. the value of the braking efficiency index, and the criterion of the difference between the diagnostic parameter value and the values assumed as acceptable for a given group of vehicles

Researchers at the Faculty of Transport and Aviation Engineering of the Silesian University of Technology conduct regular studies pertaining to the assessment of the technical condition of vehicles involved in road traffic, while problems such as the assessment methodology and technical tests, as well as the effect of technical condition on the occurrence and course of road incidents are also explored. In the years 1996–1997, comparative studies were conducted to investigate the possibility of assessing the technical condition of suspension systems using different types of control devices, and these included tests of 1,075 vehiclesa). Between 1998 and 2020, the technical condition tests performed there involved 4,461 passenger cars (category M1) and 448 commercial vehicles (category N1), covering both operational safety and their environmental impact. These tests were based on an extended methodology aligned with the guidelines established for periodic mandatory technical inspections, and comprised braking deceleration measurements and road tests for steering characteristics and straight-line driving behaviour of vehicles. The test results revealed that 31% of the defects found in the M1 category cars during the extended diagnostic tests were related to the suspension system.

Among the numerous popular vibration testing methods applicable to shock absorbers installed in passenger cars, the forced vibration method (BOGE) or the EUSAMA method and their derivatives are used most frequently (Fig. 1). [3, 4, 7, 9-11, 14, 30].

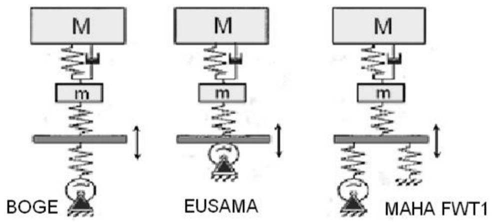

Fig. 1. Kinematic diagrams of the methods engaged to induce plate vibrations in shock absorber testing stands by the forced vibration method [8]

Both methods make use of mechanical harmonic vertical vibration exciters, causing the car wheel to vibrate as it rests on a drive-on plate of the test stand. The frequency of the forced vibrations is higher than the resonant frequency of the unsprung mass, and it comes to ca. 24 Hz. The vibration excitation cycle comprises three stages, two of which consist in accelerating the stand to a frequency higher than the resonant frequency of the suspension system, followed by the suspension system excitation at a constant frequency for a few seconds. In the final stage, after the exciter has been turned off, vibration decay begins as a result of the damping of the shock absorber, the suspension system components, and the tyre. As soon as the vibration frequency of the system reaches the resonant frequency of the suspension system, the vibration amplitude increases, and its value indicates the technical condition of the shock absorber. Damping effectiveness is determined by analysing the vibrations in the function of time (under the BOGE method), or in the function of the wheel load against the base (under the EUSAMA method). According to the modified BOGE method, implemented in MAHA-branded instruments (FWT 1), on account of the additional spring support, it is also possible to estimate load force by computational means and to establish adhesion expressed in per cent. Adhesion (road grip) is determined by measuring the maximum value of the vibration amplitude within the resonance band and of the static load of the axle subject to testing according to an algorithm specified by a given test stand manufacturer. The resultant value is interpreted as that of adhesion (in operating instructions, this value is defined as a coefficient of vibration damping in per cent). The EUSAMA method, developed by the European Shock Absorbers Manufacturers Association, consists in determining the percentage proportion between the value of a minimum wheel adhesion force within the resonance band and the value of a static wheel load. Damping efficiency is determined by the EUSAMA WE index expressed in per cent [12, 13, 15-18, 22, 24-26].

2. MODIFICATION OF THE EUSAMA TEST STAND

The EUSAMA test stand was modified by expanding the required standard measurement of the wheel load force acting on the test stand plate with an additional measurement of the excitation plate displacement as well as by altering the controls of the test stand power supply. The control system of the electric motor which delivers propulsion to the test stand plate features an inverter enabling control of the excitation parameters, including mainly the run-up and run-down times of the test stand (linear run-up time adjustment). Additionally, an accelerometer was fixed to the test stand plate to measure the acceleration of the excitation plate for comparative purposes.

3. TEST OBJECT

The results discussed in this paper were obtained in an experiment which consisted in recording displacements of the test stand's excitation plate using the Megatron RC-20-50 potentiometric sensor (linear potentiometer with a measurement range of 50 mm), a strain gauge operating within a range of 0–1,000 kg with a 0–10 mA current output, and an ICP piezoelectric accelerometer fixed to the test stand plate. Data were recorded using the Krypton 3STG data logger. The synchronous sampling rate was 20 kHz, and the resolution was 24 bits. The tests were conducted on a WV Golf fitted with standard tyres. The test stand has been shown in Figure 2.

The recording proceeded in the following stages: acceleration, operation at a constant excitation frequency, and vibration extinguishing. The excitation was adjusted by means of an inverter controlling the test stand motor operation.

The following diagram (Figure 2) illustrates the time courses of the signals recorded for the dynamic loading, displacement, and acceleration of the test stand plate. The linear frequency increase during the run-up and run-down of the test stand, set at 10 seconds, was controlled by the inverter adjusting the power supply parameters of the engine driving the test stand. Thus set, this time corresponds to measurements conducted under the typical conditions for which the EUSAMA index was established at free run-down of the test stand.

Fig. 2. Test vehicle on the test stand and elements of the measurement system

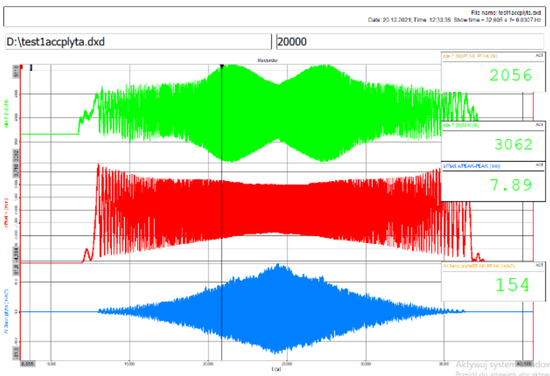

Fig. 3. Time courses of the signals recorded for the vibration test (dynamic load, plate displacement, plate acceleration)

The load and displacement values recorded during the dynamic test were as follows: minimum load – 3,062 N, peak-to-peak dynamic load difference – 2,056 N, peak-to-peak displacements – 7.89 mm.

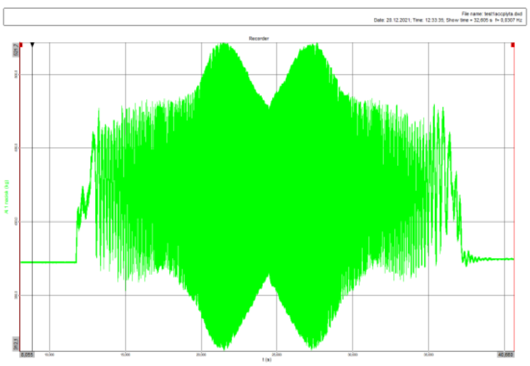

Fig. 4. Time courses of the mass changes recorded at the excitation station plate

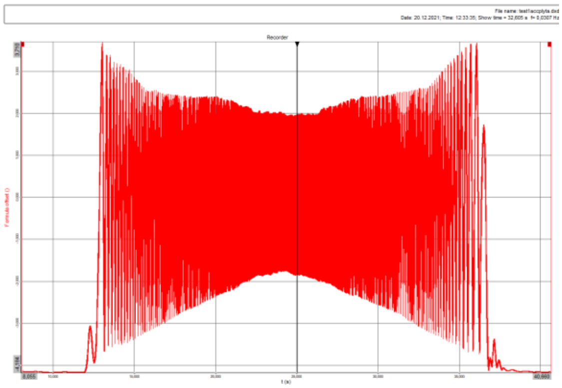

Fig. 5. Time courses of the recorded excitation plate displacements

Having analysed the displacement signal, one can observe that contact measurement of the relative displacement depends on the effect of the wheel load on the plate. As the excitation frequency increases, the relative peak-to-peak amplitude decreases from static values close to 6 mm to a value of 4 mm at the maximum excitation frequency (approx. 21 Hz). However, the amplitude value does not affect the determination of the phase angle where the zero crossing points of both signals, i.e. those of displacement and force, are analysed.

4. PHASE ANGLE DETERMINATION ALGORITHM

In order to determine the shift of the phase angle of the signals of plate displacement x (mm) and dynamic force F (N) acting on the plate, mathematical signal processing procedures were conducted. In the first iteration, constant components (offsets) were removed for the signal of displacement and mass.

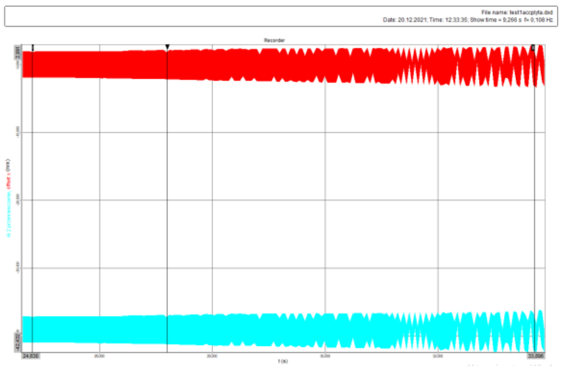

Fig. 6. Removing the offset for the displacement signal

In the next step, tapering filtration was applied to the displacement and mass signals.

Then, a frequency and angle determination algorithm defined for an analogue pulse counter was applied (the displacement and force signals were treated as analogue counters, the trigger was defined at the signal's zero crossing point, and behaviours of the 0–360° phase were determined for each test plate displacement oscillation).

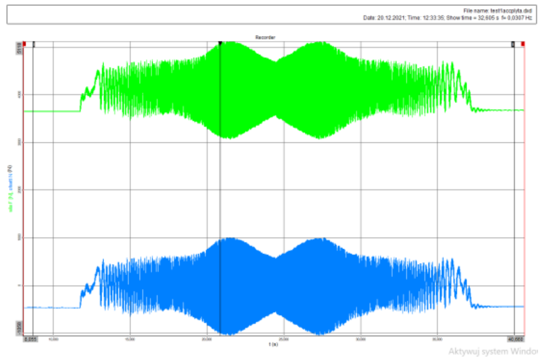

Fig. 7. Removing the offset for the dynamic load signal

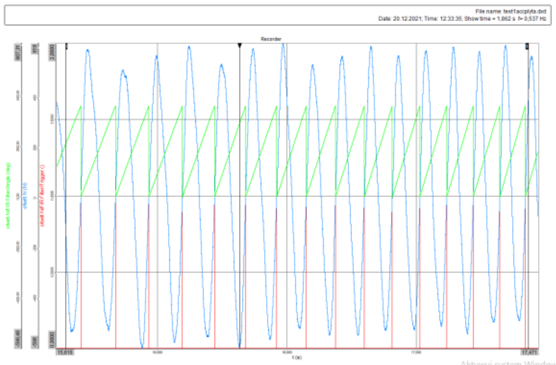

Fig. 8. Determining parameters for an analogue counter – trigger and 0–360° phase

The subsequent operation made it possible to determine the angular difference for the signal of displacement x relative to the signal of force F.

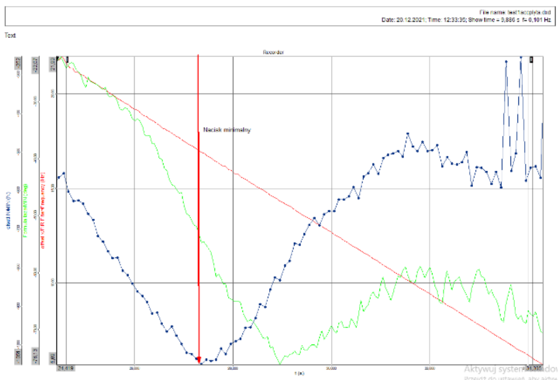

Fig. 9. Frequency change profile: excitation – red; envelope of the wheel load on the test stand plate – blue; phase angle change profile for displacement and force signals – green

5. CONCLUSIONS

The mathematical algorithm proposed for signal processing, enabling determination of the function of change of the phase angle as well as of the frequency of excitation and dynamic wheel load, makes it possible to obtain complementary diagnostic information about the technical condition of suspension systems in automotive vehicles. The diagnostic parameter can be the value of the phase angle increment in the function of the excitation frequency within the range of the resonant frequency of the unsprung masses. However, there is a certain limitation to the method proposed, namely the relatively low resolution of the phase angle determination on a small number of oscillations within the resonance band. This problem can be solved by increasing the duration of the vibration test, including the time for which the system vibrates with resonant frequency.

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