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High-power system for acoustic excitation of plates

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Abstract. *This paper introduces a device dedicated to acoustic excitation for modal analysis of plates. A particular setup is requested since the system should produce acoustic excitation with high power in the 10…120 Hz frequency range. The system comprises a signal generator, an amplifier powered by a car starter or a battery, and a subwoofer. This system permits setting the generated frequency around the resonance frequency with reasonable frequency and amplitude stability. We present the system's design and test its performance on a rectangular plate. In our laboratory experiments, we achieved the desired structural behavior.*

Keywords*: modal analysis, acoustic excitation, subwoofer, frequency estimation.*

1. Introduction

Metallic and non-metallic structures can suffer damage or deviations from the constructive parameters for various reasons. These can be local or spread along the structure [1]. To find the damage parameters, we need to know the measured values of the resonance frequencies for different modes of the component elements of these: beams, plates, etc. Since the 1990s, various vibration-based defect detection methods have been described in detail in the literature [2]-[4]. Since defects produce a relatively small change in the modal parameters, a very accurate estimate of the changes is essential [5].

Structural excitation for modal analysis can be done by the environment in which the structure operates [6], or controlled excitation can be applied by an operator through a suitable system [7]. Different methods of applying controlled excitation are mentioned in the specialized literature: acoustic waves, piezoelectric elements, magnetic coils, or shakers.

The devices that produce these controlled excitations have different powers, depending on the field and place of use, the type of defect sought, and other limitations.

We propose a subwoofer for excitation, whose large surface area is proper to generate controlled excitation of metallic and non-metallic plates. The subwoofer has a high power (up to 300 W true RMS). It permits inducing mechanical oscillations with controlled frequency and amplitude to obtain different vibration modes of the different types of structures.

2. Design of the actuation system

Generally, modal analysis equipment consists of the excitation and the signal acquisition and processing system. This paper presents an acoustic excitation system, with the configuration illustrated in the block diagram's upper part (Figure 1). The excitation system's requirements include adjustable frequency, controlled time length, and precise positioning.

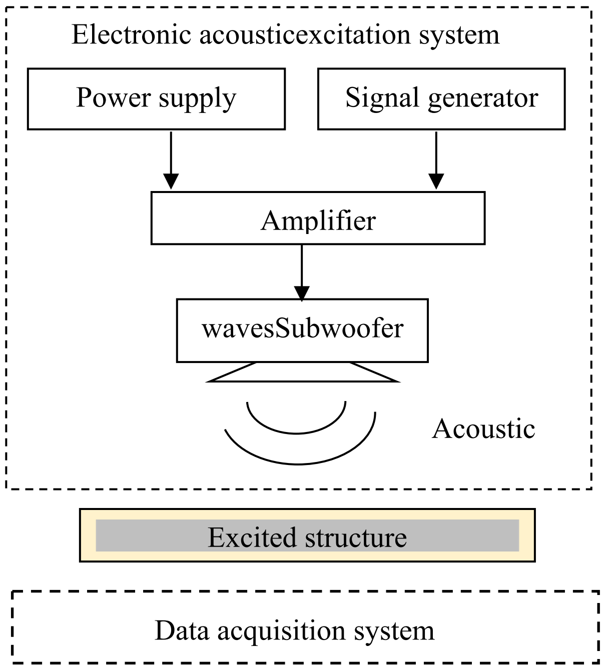

Figure 1. Actuation /acquisition system's functional block diagram

The excitation system should be able to generate frequencies in the range of 10-100 Hz. The acquisition system, which is not the aim of this paper but is used to prove the effectiveness of the excitation subsystem, can acquire accelerations up to 100 m/s^2 and accurately estimate the frequencies of short-time signals.

The developed acoustic excitation subsystem consists of a signal generator to produce a sinusoidal signal with adjustable amplitude and frequency, a subwoofer for audio bandwidth, an amplifier that drives the subwoofer, and connecting wires.

The used subwoofer is KIKER VCompS12, presented in Figure 2, and has the following characteristics:

- 300 W Continuous Power (watt RMS) at 2 Ohm
- 600 W Peak Power at 4 Ohm.

Since the sub-woofer's impedance is low, for practical reasons, we need a car amplifier powered at 12 Vdc.

Figure 2. Front and side view of the subwoofer KIKER VCompS12

The bandwidth of the subwoofer is from 25 to 120 Hz. If it is necessary to produce frequencies lower than 25 Hz, the frequency drop of the subwoofer can be compensated by increasing the gain using an ultra-low frequency amplifier.

One such amplifier is the BOSS Audio Systems MODEL R1600M. According to [18], it has the following parameters: Class A/B, Monoblock, MOSFET power supply; 1600 watts at 2-ohms x 1 max, 800 watts at 4-ohms x 1 max, High & low-level inputs; soft turn-on circuit, thermal overload speaker and short-circuit protection; Power &protect LEDs, variable low pass crossover 50–250 Hz; Variable bass boost 0–12 dB, variable gain control, speaker impedance 2–8 ohms; THD at RMS output: <0.01%, S/N ratio 102 dB, frequency response 9 Hz–130 Hz.

As the subwoofer has high power and frequencies around 50Hz are also generated, problems with grid network power noise can occur. Two usual solutions for powering the amplifier (each with advantages and disadvantages) can be used: batteries or a power rectifier.

Batteries are the best sources of direct current electricity supply. Unfortunately, they are heavy and cannot withstand a wide range of ambient temperatures without affecting their performance, discharge over time, etc.

Power rectifiers are more practical and can be moved more quickly. As a disadvantage, we mention that the power rectifiers can introduce noises with frequency multiples of the power grid frequency (especially at high powers and if they are not well matched to the amplifier) and are dependent on the presence of the power grid supply voltage. This last aspect can be eliminated today with portable electricity generators.

Fortunately, analyzing structural defects does not imply continuous use of the system but an intermittent use of relatively short duration. This particularity benefits both power supply methods: the batteries do not discharge during measurements, and a car starter can be used as a power rectifier, successfully replacing a battery for a short time.

One such car starter is the ever Active CBC-40 V2 charger, presented in Figure 3, which has start aid and the following main characteristics:

- Electronically stabilized output voltage - automatic charging process;
- Adjustable charging current - from 5A to 40A, for 12V/24V batteries;
- Digital ammeter;
- Max. charging current: 60A;
- Max. current for starting aid function: 300A;

Figure 3. Overview of the car charger

The charging current is enough to supply a 300 W amplifier, which can drive the subwoofer to the maximum RMS continuous power.

Figure 4. Overview of the front panel of the signal generator

The signal generator we use is of type BK PRECISION 4053 B and can generate stable and precise sine, square, triangle, pulse, noise, DC, and arbitrary waveforms [8]. The primary output voltage can be varied from 0 to 10 Vpp into 50 ohms (up to 20 Vpp into open circuit), and the secondary output can be varied from 0 to 3Vpp into 50 ohms (up to 6Vpp into open circuit). The modes of the generated signals can be modulated, swept, or burst. Modulation can be amplitude and frequency modulation (AM/FM), double side-band amplitude modulation (DSB-AM), amplitude and frequency shift keying (ASK/FSK), phase modulation (PM), and pulse width modulation (PWM). It also has a built-in counter.

Frequency accuracy is +25ppm, the resolution is 1μHz, and the bandwidth is 1μHz to 10MHz.

Amplitude accuracy is ± (1 % + 1 mVpp of setting value) for 2 mVpp – 10 Vpp into 50 Ω (4 mVpp – 20 Vpp into open circuit), ≤ 10 MHz amplitude and the normal output impedance is 50 Ω for both channels.

Sweep shape can be linear or logarithmic, up or down. Time sweep is from 1ms to 500s, triggered internally, externally, or manually for a sinusoidal, square, ramp, or arbitrary waveform.

In this experiment, we use a sinusoidal frequency close to a plate's first natural frequency. Hence, we obtain a resonant response of the structure.

3. Testing the excitation system on plates

The excitation system is tested on a steel plate with the dimensions a = 950 mm and b = 400 mm. The thickness of the plate, which is clamped on the contour by fixing it in a specially designed restraining system, is t = 2 mm. The first natural frequency is determined with the FEM in [9], and we found it is f_1 = 73.047 Hz.

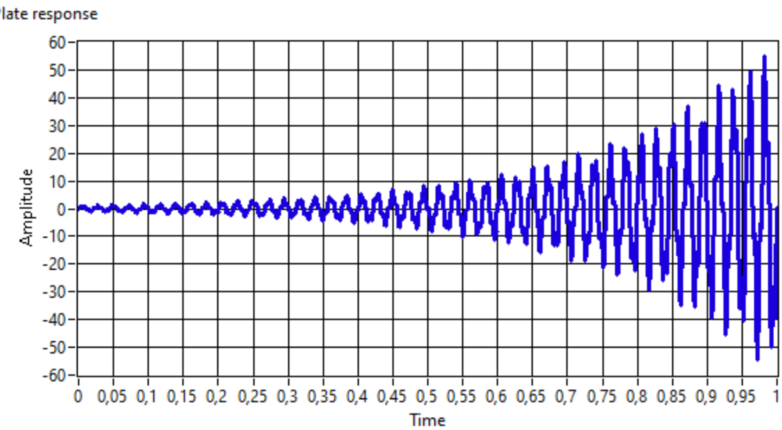

Figure 5. Response of the lightweight structure (plate clamped on the contour)

The signal obtained in the first second of excitation is presented in Figure 5. The acquisition system is comprehensively described in [10]. One can observe that the amplitude increases rapidly, and the alteration of the first mode is minimal.

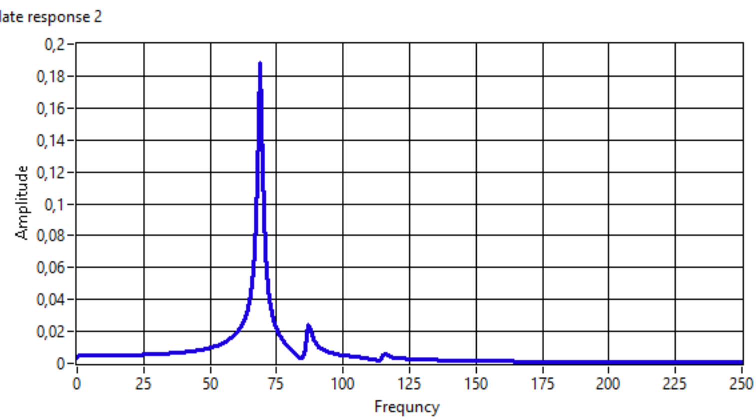

Figure 6. Response of the lightweight structure in the frequency domain

The relevant harmonic component at approximately 70 Hz can be observed in Fig. 6, which confirms the clear pseudo-sinusoidal evolution of the signal. Given the excellent quality of the response signal, which demonstrates that we control how the energy is transferred to the structure, we conclude that the designed system is proper for experimental modal analysis.

4. Conclusion

The paper presents a non-contact method to excite lightweight structures with acoustic pressure with controlled energy. The control concerns the frequency, thus the excited vibration mode, and the amplitude of this mode. We proved that when using a controlled excitation, the signal is close to a pseudo-sinusoidal signal, whose spectrum contains a strong harmonic component and several harmonics with low amplitude. This spectrum is proper for estimating the frequencies with high accuracy. The disadvantage is the one-by-one search of the harmonic components and their frequency. In the following studies, we will test the excitation system with a swept-sine signal to excite more vibration modes and get their frequencies.

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