Natural Frequency Analysis of a 3D Printed ICE Velocity Stack for a Racing Car

Kristina Georgieva, Tsvetomir Gechev, and Krasimir Nedelchev

***Abstract*—The paper deals with the design and production processes of a velocity stack for the intake system of a racing car's engine. The velocity stack was created using FDM 3D printing (additive manufacturing). This production technology, combined with the use of heat-resistant polymer materials, is gaining popularity in the automotive industry, because it saves significant amount of time and financial resources. In the paper firstly the advantages and disadvantages of the velocity stack are discussed, then its structural and production parameters are presented. In order to prevent resonance in the car and thus to prevent damage, it is important to know the natural frequencies of all its elements. For this reason, an analysis was made of the first two natural frequencies of the produced velocity stack, both in a simulation software environment and experimentally. As a conclusion the results from the studies are presented and compared. The first natural frequency equals to 439 Hz and 377 Hz for the simulation and experiment respectively. The second natural frequency is 960 Hz and 883 Hz for the simulation and experiment respectively.**

***Keywords*—3D printing, sports car, intake system, velocity stack, natural frequency, vibration, bell mouth.**

I. Introduction

A velocity stack is a tubular device used in internal combustion engines (ICEs) which is placed in the beginning of the intake system, usually just before the manifold. It is used in high-powered, mostly sports-racing cars and motorcycles [1], as each cylinder has a single velocity stack installed. It possesses the following functions:

- to convert the fast and turbulent flow into a laminar one, reducing hydraulic resistance and improving volumetric efficiency;
- to contribute to increasing the power of the engine and the car as a result of the improved volumetric efficiency;
- to modify the dynamic tuning range of the intake system by changing its length.

The usage of a velocity stack also reduces the length of the intake system and thus creates an acoustic effect that some sport car enthusiasts may find attractive. Naturally, in addition to the advantages, this device also has disadvantages. The main drawback is that due to its installation and function, the air filter, air box, and intake ducting are not present. The lack of an air filter in particular means that dust, solid particles and other contaminants would easily enter the engine's cylinders and cause them wear or damage. Because of this the velocity stack is mostly used in racing cars, where power is not compromised and engine repair is frequent.

However, there are configurations where the air filter [1] and the temperature sensor for the intake system, are mounted precisely on the velocity stack. Another disadvantage is that the acoustic effect can actually be regarded as an unpleasant noise.

There are various velocity stack geometries and designs, e.g.:

- straight – it differs from a straight pipe only by a change in the edge;
- conical;
- curved, depending on the profile, for example in the shape of a trumpet or bell (bell mouth);
- with adjustable length, composite;
- with air filter mounting flange.

The choice of construction depends on the specific goals of tuning the engine, as well as the conditions in which it will operate. In Fig. 1 different geometries and the change of intake amount of air in terms of volume are presented [2].

The natural frequencies of the velocity stack need to be studied to make sure they do not coincide with the natural frequencies of the engine or the chassis of the vehicle. If they do coincide, the velocity stack could break. Normally the eigenfrequencies of a vehicle's chassis are low in value – a study of a truck's chassis reveals that the first six of them are below 40 Hz [3]. In the case of the engine, the natural frequencies depend on the size, type, structure, applied materials, and number of different components used in it, which usually are separately studied for a given engine.

The research of natural frequencies of 3D printed parts and models focuses on beam models, or other types of test bodies, as the main variation in the bodies is regarding the material used [4], infill pattern and density [5], print orientation, or other print parameters. Studies of natural frequencies of specific engine parts made via 3D printing are a novelty.

A. Design and Application

In the current study a type 10 velocity stack of the ones shown in Fig. 1 was designed and manufactured. The choice of type 10 is due to its easy to implement and produce geometry, yet the relatively high increase in air intake. The velocity is adapted for installation on a Lada Samara (BA3 2108), refitted for car racing, with a displacement of 1566cc, cylinder diameter D = 84.55 mm (pistons from Fiat; connecting rods from BMW; block, head and crankshaft from Lada Niva 1700cc), and piston stroke S = 69.7 mm. The car and the installation location with the velocity stacks are presented in Fig. 2.

Received: 03.04.2025
Published: 31.05.2025
https://doi.org/10.47978/TUS.2025.75.02.004

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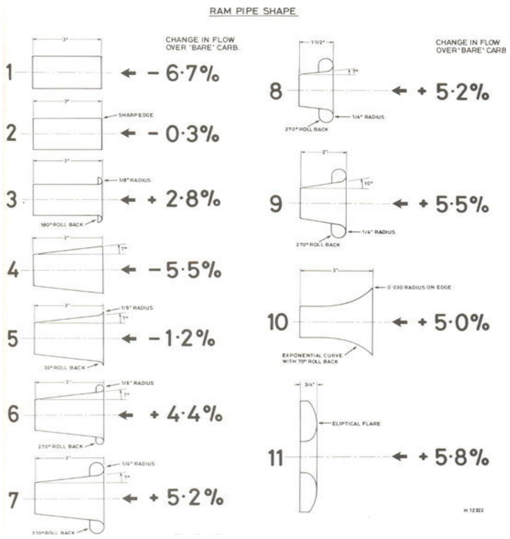

Fig. 1. Different velocity stack geometries.

II. Design and Production of The Velocity Stack

Mounting is realized by incorporating mounting ears in the construction and by using locking screws. The geometric parameters of the designed device are presented in Table 1, where base diameter is considered the diameter in the side where the mounting ears are located, while tip diameter is the diameter at the end of trumpet-like shape, where air enters the intake system. In Fig. 3 the model of the velocity stack is shown as it is in the SolidWorks engineering software that is used for the modelling and simulation.

TABLE 1
GEOMETRICAL PARAMETERS OF THE VELOCITY STACK

Parameter	Value, unit
Base diameter without ears	66.5 mm
Tip diameter	95 mm
Height	86 mm
Volume	63.33 cm^3
Wall width	3 mm

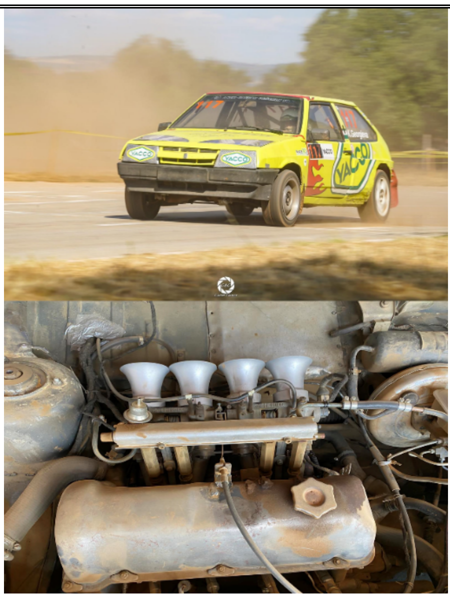

Fig. 2. Photos of the racing car in which the velocity stacks are used (above) and mounting location of the stacks in relation to the engine (below).

Fig. 3. Image of the modelled velocity stack within the environment of the software product SolidWorks.

A. Production and Used Material

The used production technology is FDM 3D printing – Fused Deposition Modelling, which is actually the most common and cheapest method for additive manufacturing.

It uses polymer materials (filaments) that are wound on a roll a), Fig. 4. The filament is fed and melted through a nozzle that is placed within the print head b) and is being laid layer by layer on a print plate e) to create a printed object d) – [6], Fig. 4. The movements of the print head and plate are realized by using motors c) and are controlled by a controller depending on the printed part, printing parameters, and the set printer structure and available space f).

In the current study, a Bambu Lab X1 Carbon printer was used and the applied material was acrylonitrile styrene acrylate (ASA), which has strength properties close to those of the classic plastic – ABS, but is resistant to ultraviolet light. In Fig. 5 the printer and filament rolls are shown. ASA was chosen specifically for its high temperature and UV resistance.

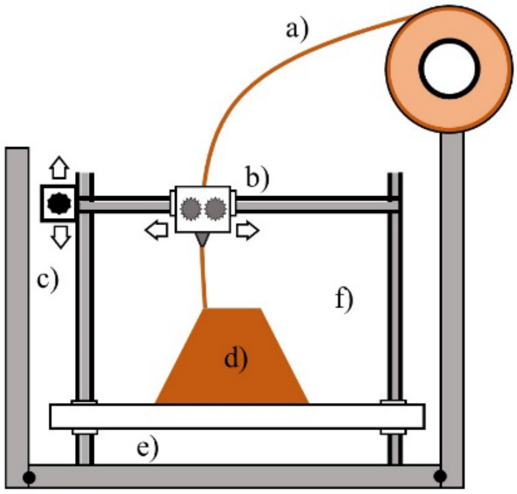

Fig. 4. Schematic of the FDM 3D printing.

In Table 2 are presented the print parameters for the velocity stack, and in Table 3 – the technical parameters of the used material according to its producer [7]. The testing is performed according to ISO 527, GB/T 1040 standard.

Fig. 5. Photo of the used Bambu Lab X1 Carbon printer.

TABLE 2
PRINT PARAMETERS

Parameter	Value, unit
Nozzle temperature	260 °C
Print plate temperature	90 °C
Filament diameter	1.75 mm
Nozzle diameter	0.4 mm
Outer wall loops	2
Infill density	100 %
Infill type	Rectiliniar
Print speed	120 mm/s
Infill/Wall overlap	15%

TABLE 3
TECHNICAL PARAMETERS OF THE USED FILAMENT

Parameter	Value, unit
Type	ASA
Density	1.13 g/cm^3 at 23 °C
Tensile strength (X-Y)	38.6 ± 0.3 MPa
Tensile strength (Z)	30.0 ± 0.5 MPa
Elastic modulus (X-Y)	2174.6 ± 41.1 MPa
Elastic modulus (Z)	1971.6 ± 78.8 MPa
Elongation at break (X-Y)	4.4 ± 1.0 %
Elongation at break (Z)	2.4 ± 0.1 %

III. SIMULATIONAL ANALYSIS OF THE NATURAL FREQUENCY

Based on the model presented in Section II of the paper, a frequency analysis was performed in the SolidWorks software environment. For this purpose, a material was defined – plastic, with identical technical parameters as to the ones given in Table 3. After that, a mesh of finite elements was created, composed of 60044 triangular elements with length of each side being 2 mm. The places for attachment (fixtures) are the surfaces with holes for the locking screws – Fig. 6. After determining the fixtures and generating FEM mesh, the simulation was performed and the natural frequencies were obtained.

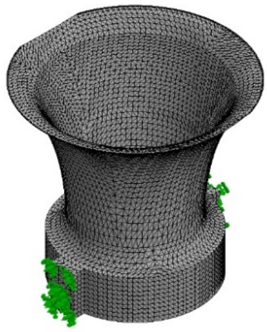

Fig. 6. Image of the velocity stack with set fixtures and FEM mesh in the software product SolidWorks.

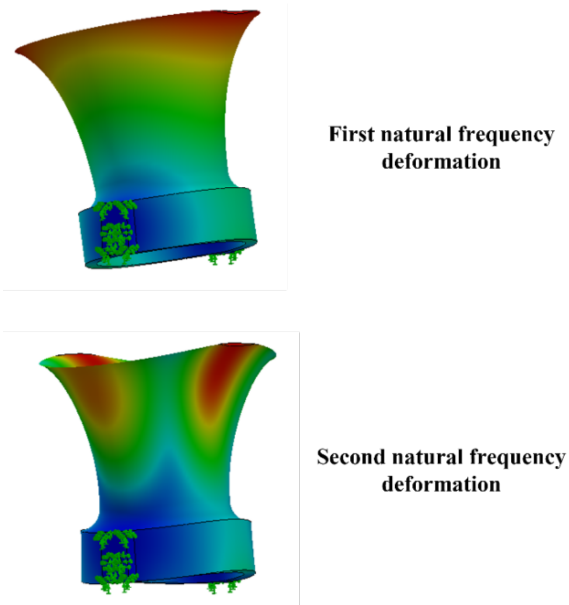

Fig. 7. Deformations of the velocity stack as a result of the natural frequencies.

In Fig. 7 the deformations of the velocity stack as a result of the natural frequencies are presented. The values for the first two natural frequencies in the simulation study are presented in Table 4.

TABLE 4
NATURAL FREQUENCIES IN THE SIMULATION

Natural frequency	Value, unit
First	439.16 Hz
Second	960.08 Hz

IV. EXPERIMENTAL ANALYSIS OF THE NATURAL FREQUENCY

The experimental setup is a Vibration Test System TV 51140 by the company TIRA Schwingtechnik. It consists of an electrodynamic exciter with an operation frequency range of 2 to 6500 Hz [8], and an amplifier. The test piece – the produced velocity stack, is mounted on the exciter by means of an aluminum profile, corners and fasteners, as shown in Fig. 8. The natural frequency of the object is identified, based on structural noise generated by it during the study. The noise was measured with a SVAN 979 noise meter. The results for the first two natural frequencies for the experiment are presented in Table 5. The error for the first frequency is 14.15%, and for the second – 8.03%. It can be concluded that the simulation is comparable to the experiment within 15% error and can be used instead of the experiment with an appropriate correction factor suitable for such test objects.

Fig. 8. Photo of the experimental setup with mounted velocity stack on the exciter.

TABLE 5
NATURAL FREQUENCIES IN THE EXPERIMENT

Natural frequency	Value, unit	Error
First	377.00 Hz	14.15%
Second	883.00 Hz	8.03%

V. CONCLUSIONS AND FUTURE RESEARCH

The results of the simulation and experimental studies related to the determination of the first and second natural frequencies differ by less than 15%, which shows that simulations can be used to optimize the shape and dimensions of the studied object.

More research needs to be conducted in order to determine the eigenfrequencies of other components of the specific engine used and to compare them with the natural frequencies of the produced velocity stacks. Then it would be possible to determine if the obtained frequencies of the stack are satisfactory.

Future research of the team will be focused on optimization of the shape of the studied object taking into account its aerodynamic characteristics through CFD and experimental analyzes, as well as natural frequency determination of other engine components.

ACKNOWLEDGEMENT

This work was financially supported by the European Regional Development Fund within the Operational Programme “Science and Education for Smart Growth 2014 - 2020” under the Project CoE “National center of mechatronics and clean technologies“, BG05M2OP001-1.001-0008.

REFERENCES

[1] F. Fauzun, C. Yogiswara, “The Effect of Bellmouth Radius and Venturi Restrictor Length on The Power and Torque of BM-9’s Engine”, *Transdisciplinary Research and Education Center for Green Technologies,* Kyushu University, vol. 8, no. 2, pp. 477-483, 06, 2021, DOI: 10.5109/4480732.

[2] D. Vizard, “Chapter 6 – Ram Charging”, Tuning BL’s A-Series Engine, Haynes Publishing Group, England, 1989.

[3] M. Forouzan, R. Hoseini, “Dynamic Analysis of a Modified Truck Chassis”, *International Journal of Advanced Design and Manufacturing Technology*, vol. 3, September 2010.

[4] C. Senthamaraikannan, B. ParthaaSarathy, S. Surya, S. Rajan, “Study on the free vibration analysis and mechanical behaviour of 3D printed composite I shaped beams made up of short carbon fiber reinforced ABS and PLA materials”, *Materials Today: Proceedings*, 2023, DOI: 10.1016/j.matpr.2023.07.141.

[5] P. Yadav, Abhishek, K. Singh, J. Bhaskar, “Effect of Infill Percentage on Vibration Characteristic of 3D-Printed Structure”, *Advances in Manufacturing and Industrial Engineering*. ICAPIE 2019, DOI: 10.1007/978-981-15-8542-5_49.

[6] T. Gechev, “A short review of the 3D printing methods used in the automotive industry”, *Bulgarian Journal for Engineering Design,* Technical University of Sofia, vol. 44, pp. 67-76, 11, 2021.

[7] Polymaker, “Technical Data Sheet, ASA”, V5.3, Available: www.polymaker.com.

[8] TIRA Schwingtechnik, “Vibration Test System TV 51140 technical sheet”, Available: www.tira-gmbh.de.