

Article

Enhanced, Seamless Ultrasound Introduction Unit for Thermoplastic Melt Treatment

Marc René André Sparenberg , Jan-Uwe Reinhard Schmidt , Maik Titze  and Hans Peter Monner 

German Aerospace Center (DLR), Institute of Lightweight Systems, 38108 Braunschweig, Germany; jan-uwe.schmidt@dlr.de (J.-U.R.S.); maik.titze@dlr.de (M.T.); hans.monner@dlr.de (H.P.M.)

* Correspondence: marc.sparenberg@dlr.de; Tel.: +49-531-295-3078

Abstract: Ultrasonic power stimulation of polymers has been employed to modify their properties for various industrial applications. It is used to disperse particles in polymers or to impregnate continuous fiber-reinforced filaments. These processes operate under extreme conditions, involving temperatures exceeding 400 °C and pressures reaching up to 60 bars. Traditional sound introduction systems rely on moving horns within cavities, which pose significant challenges in maintaining clean environments. The moving horn makes it inconceivable to seal such sound introduction systems. To address these limitations, an innovative tool that incorporates only sealed components capable of introducing sound energy without employing cavities was developed. This technology focuses on optimizing eigenfrequencies to efficiently transfer motion into the polymer channel while minimizing disturbing vibrations and sealing issues. The simulation results reveal the mode of operation between the fourth and fifth resonance of the tool. The measurements of the tool validate this theory, indicating a range of operation between 18.5 kHz and 19.5 kHz. With an amplitude of 15 µm, resulting in a minimum power introduction of 224.03 W/cm² in PLA, the average flow rate gain is 13.6%. This new design reduces the risk of blockages and damage in the processed goods and minimizes the force required to process the polymer.

Keywords: design; seamless; ultrasonic; polymer; fiber; impregnation; fiber impregnation



Academic Editor: Elisabetta Sieni

Received: 3 January 2025

Revised: 28 January 2025

Accepted: 3 February 2025

Published: 6 February 2025

Citation: Sparenberg, M.R.A.; Schmidt, J.-U.R.; Titze, M.; Monner, H.P. Enhanced, Seamless Ultrasound Introduction Unit for Thermoplastic Melt Treatment. *Designs* **2025**, *9*, 18. <https://doi.org/10.3390/designs9010018>

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Polymeric treatment has been implemented in various industrial processes, i.e., applications that involve dispersing particles or impregnating fibers in a polymeric melt [1,2]. However, these polymers are favored to be used in performance applications. Either particles or fibers can change the material properties dramatically. The base polymers need to be modified in order to utilize the benefits of the composite between the polymers and additives [3,4]. This process is mainly used to improve their properties [5–7]. Ultrasound technology plays a crucial role in enhancing the effectiveness of this process [8,9]. Research has demonstrated that ultrasound treatment enhances particle dispersion in melts and fiber impregnation [10,11]. One specific use case is the production of continuously reinforced filaments for 3D printing [12]. Furthermore, by introducing shear forces and energy into the polymer, its viscosity is reduced, easing the flow through narrow channels typically found in processing tools [7,13]. However, current implementations of these systems introduce secondary issues that vary in disruptive impact depending on the material system used. One notable problem associated with direct contact horns is the creation of edges and undercuts in tools, potentially damaging semi-finished products, facilitating blockages, or

increasing forces required for material transfer through the system. The mechanical setup of existing ultrasonic sound introduction units consists of a horn in direct contact with the melt, transmitting energy through direct impact during operation at frequencies of up to 40 kHz and amplitudes reaching 30 μm . The relative movement of the horn compared with the surrounding components poses significant sealing challenges [14]. Additionally, the ultrasonic treatment reduces the viscosity within the designated cavities and enhances the secondary flow (see Figure 1). Various approaches have been developed to address these issues:

1. Attempting to achieve tight seals, resulting in relatively low-amplitude movements [15].
2. Creating a cavity in part of the horn and clamping it in its first wave node, resulting in the necessity of a dead space filled with the polymer. However, without the implementation of a venting system, the derogated polymer flows back into the primary melt stream [16].

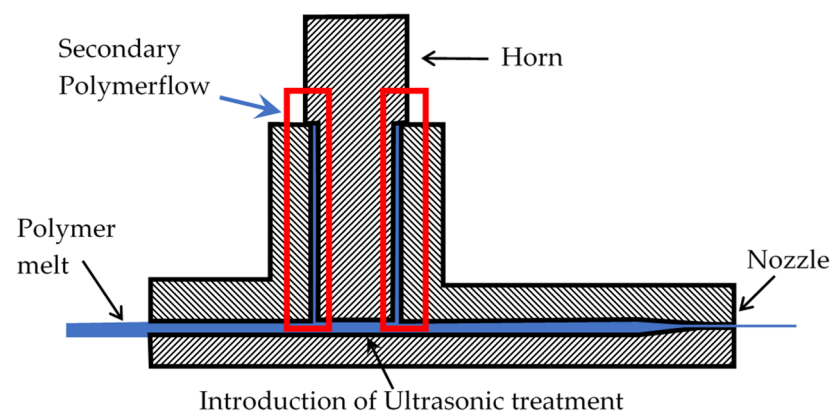


Figure 1. The implemented horn generates undercuts and enables a secondary polymer flow, particularly during operation. The ultrasonic treatment reduces the viscosity within the designated cavities and enhances the secondary flow relative to the polymer flow to the nozzle.

From an economic perspective, these sealing solutions increase costs without adding value to the final product. Therefore, a totally sealed tool would address these challenges. Such a tool could potentially be achieved by either sealing the horn or by modifying the mechanism of sound introduction, which is challenging to achieve at high frequencies. But still, theoretical concepts for such approaches remain largely unimplemented due to practical challenges in achieving tools that operate in eigenforms at applied frequencies and amplitudes while also maintaining the ability to insert sound energy and seal against the rest of the production line without transmitting vibrations [17].

To realize a seamless mixing element, the polymer should stay encapsulated while receiving sound energy from the ultrasonic transducer. To achieve this, a modal design to arrange an encapsulated ultrasonic sound introduction unit is presented (see Figure 2).

The new design ensures ultrasonic power transfer to the polymer through a counter-phase swinging mass that compresses the channel. Solid joint arrangements allow the necessary deformation without creating cavities. The absence of cavities prevents the polymer from generating secondary flows, which enables the tool to prevent edges or undercuts, reduce potential damage to semi-finished products and the risk of blockages, and minimize the forces required for material transfer through the system.

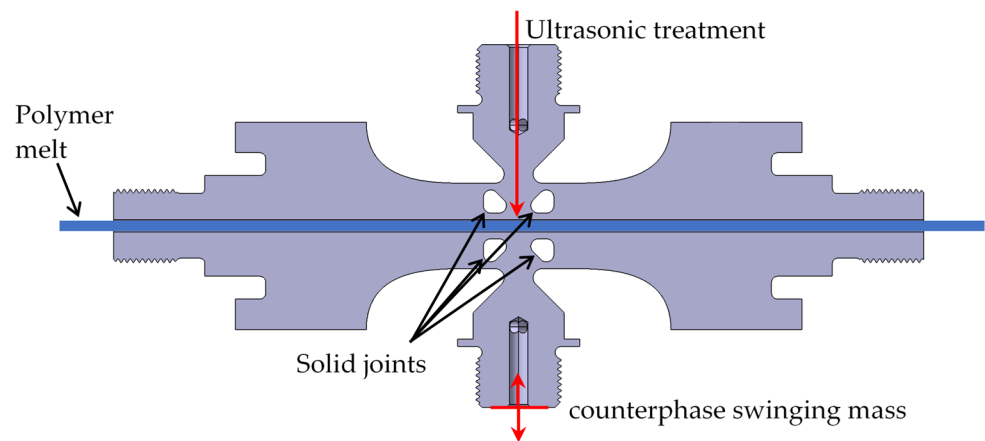


Figure 2. The encapsulated ultrasonic sound introduction unit. The closed channel prevents a secondary polymer flow, while the counter mass enables an efficient sound power transfer.

2. Materials and Methods

2.1. Material

Two polymers were processed in the subsequent experiments. The first material was “Ingeo™ Biopolymer 2003D” manufactured by “NatureWorks” (Plymouth, MN, USA), which is based on polylactic acid (PLA) with a melting point of 210 °C. Throughout this research, only the base material PLA will be referenced. The second material employed was “Dahlpram® 009” produced by “Airtech Europe Sarl” (Niederkorn, Luxembourg). This product is specifically designed for cleaning purposes within the 3D-printing sector and exhibits a wide range of processing temperatures (200–400 °C). In the following study, this material will be referred to as the cleaning material. The final tool was manufactured using Toolox44, a high-performance steel alloy characterized by its exceptional dimensional stability during processing. This choice of material enabled the efficient production of the tool itself, ensuring optimal precision and consistency throughout the production process.

2.2. Modeling

A modal design minimizes the structural rigidity to optimize sound power transmission into the polymer being mixed. Figure 3 shows a graph illustrating the dynamic stiffness over frequency of a structure near its first eigenfrequency. The lowest point of stiffness represents the resonance frequency and decreases the structure’s stiffness to the damping of the structure (a tuning fork’s functional principle) [18–20]. This effect allows us to maximize the transmission of sound power from the ultrasonic transducer (Hielscher, type UIP1000hDT transducer/sonotrode, Teltow, Germany) to the polymer through a closed channel.

The proposed closed seamless mixing element employs an encapsulated polymer system that allows transmitting the ultrasonic power from an ultrasonic transducer. The device includes two specially designed masses configured to exhibit the modal swinging mode at the operational frequency. These masses compress the channel that encloses the polymer, as illustrated in Figure 4. The mixing tool is engineered to operate in resonance within a predetermined frequency range (19.2–19.8 kHz) set by the ultrasonic transducer. The key design considerations include (1) mass dimensions, (2) the integration of a cooling system, (3) the decoupling of vibration, and (4) maintained thermal conductivity.

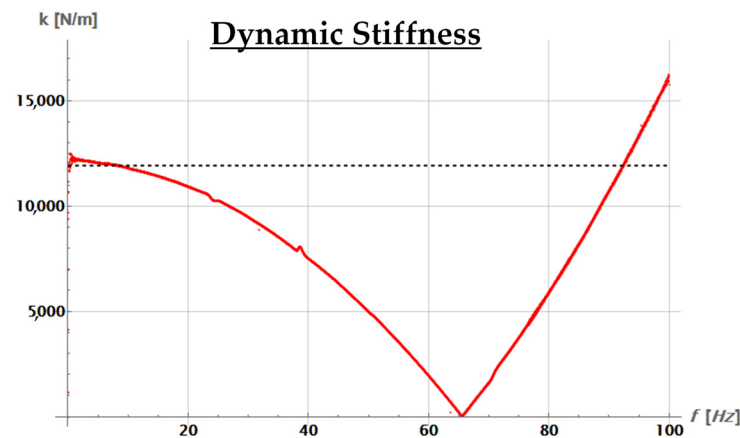


Figure 3. The illustrative trajectory of dynamic stiffness over frequency for a structure in the range of its first eigenfrequency.

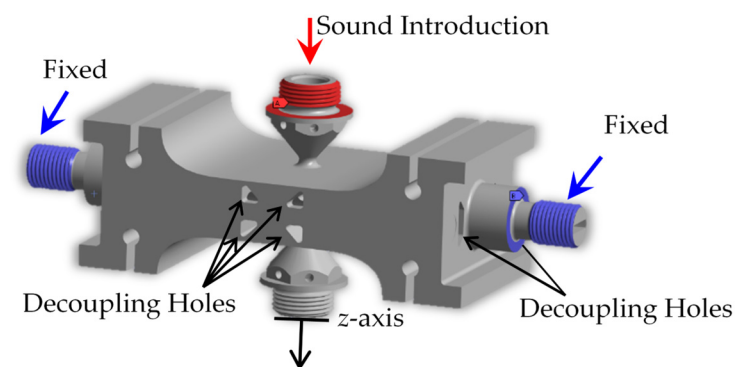


Figure 4. The boundary conditions of the sound introduction unit in ANSYS. The ends of the channel are fixed, and the sound introduction occurs at one of the two masses perpendicular to the channel.

These considerations focus on the compatibility with existing production lines. The oscillating masses were designed with a 15 mm key width and cooling holes to function as a heat break. To mitigate potential interference with sensitive components due to vibrations, decoupling holes were drilled along and crosswise to the channel. However, heat transfer remains possible due to the solid joint connections to the channel. Harmonic analysis conducted using ANSYS 2022 R2 software demonstrated the expected deformation of the masses during operation. The material model was based on the material “Toolox44”, with the following properties: a density of 7.85 g/cm³, an E-modulus of 210 GPa, and Poisson’s ratio of 0.31. The expected deformations were small and allowed a linear calculation with a mesh made of 1.9 million knots and 1.3 million elements. The left-hand side of Figure 5 presents the three-dimensional representation of the simulation model, revealing the displacement behavior of the mass positioned on the opposite side of the sound introduction unit. This visualization focuses attention on the boundary conditions influencing the dynamic response of the system under investigation. The model features fixed end-mounting conditions for the polymer-filled channel and directional sound introduction perpendicular to one of the two masses. The side view on the right side of Figure 5 illustrates the effect of decoupling holes parallel to the polymer channel during compression. These holes facilitate the deformation of the channel without transferring vibrations to the heating elements. The decoupling holes perpendicular to the channel separate the sound introduction area from the production line, visible in the three-dimensional representation on the left side of Figure 5. The frequency response evaluation was facilitated by assessing the speed of the counter-mass, influenced by the force introduction. To validate the initial ANSYS model, three-dimensional printed prototypes were employed.

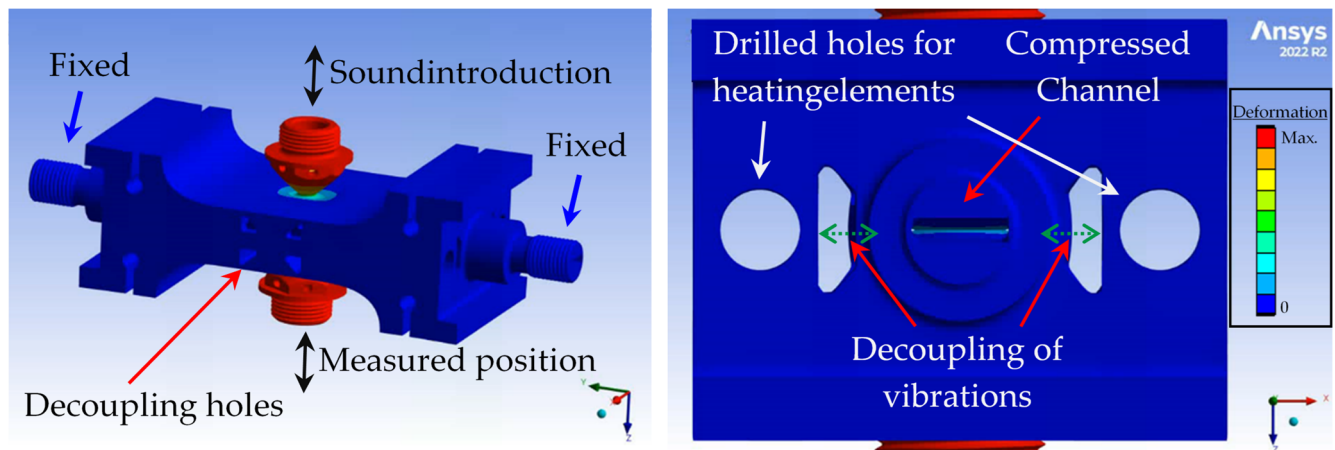


Figure 5. Principle of the sound introduction unit in operation. **(Left):** Operating conditions of the sound introduction unit. The ends left and right are fixed, and sound introduction occurs at the upper mass. The lower mass begins a counter movement at the corresponding resonance frequency without transferring the resulting deformation to sensitive components. **(Right):** The side view illustrates the decoupling of the generated vibrations, as well as the compression of the channel.

To validate the simulated results against experimental data before manufacturing the tool out of Toolox44, the material model utilized in the simulation was modified to match the “VeroBlue” material properties from Stratasys (Eden Prairie MN, USA), with the following characteristics: a density of 1.19 g/cm^3 , an E-modulus of 2.5 GPa, and Poisson’s ratio of 0.42.

2.3. Experimental Setup

Figure 6 illustrates the impedance test stand utilized for determining the dynamic properties of a VeroBlue material-based model (printed with Stratasys, Objet260 Connex3). In this configuration, a shaker (Bruel & Kjaer, Type 4809 Vibration Exciter/Shaker, Nærum, Denmark) excites an impedance sensor (Bruel & Kjaer, Type 8001 Impedance Head). This sensor is designed to measure both force and velocity alongside the sound introduction unit. Simultaneously, a vibrometer (Polytec GmbH, Type PDV-100 vibrometer, Waldbronn, Germany) is employed to record the velocity of the counter-mass that is on the opposite side. The dataset is recorded with an FFT analyzer (Onosokki, type CF-7200, Yokohama, Japan), while the signal generator (Yokogawa, type FG300) controls the shaker amplifier (Kepco, type “Bipolar Operational Power Supply/Amplifier”, Samseong-dong, Seoul). And the force and velocity signal from the impedance sensor is amplified by the signal conditioner (Bruel & Kjaer, type “Nexus Conditioning Amplifier”). The identification of the eigenfrequencies can be performed by plotting the velocity over frequency. Peaks in velocity occur in modes of interest. The velocity of the counter-mass, resulting from the force introduction, can be evaluated as a frequency response. From the simulation validated by 3D-printed models, four crucial frequencies arise in the sonotrode excitation range (see Figure 7). The third eigenfrequency (from the left) is a bending mode of the sound introduction unit, corresponding to a bending mode, potentially causing damage to the heating elements. The fourth eigenfrequency represents the optimal operational mode. The following minimum has similar deformation properties. However, the compression of the channel is impaired because the counter-mass has a minimal displacement. The fifth eigenfrequency induces oscillation along the channel and should, therefore, not be stimulated.

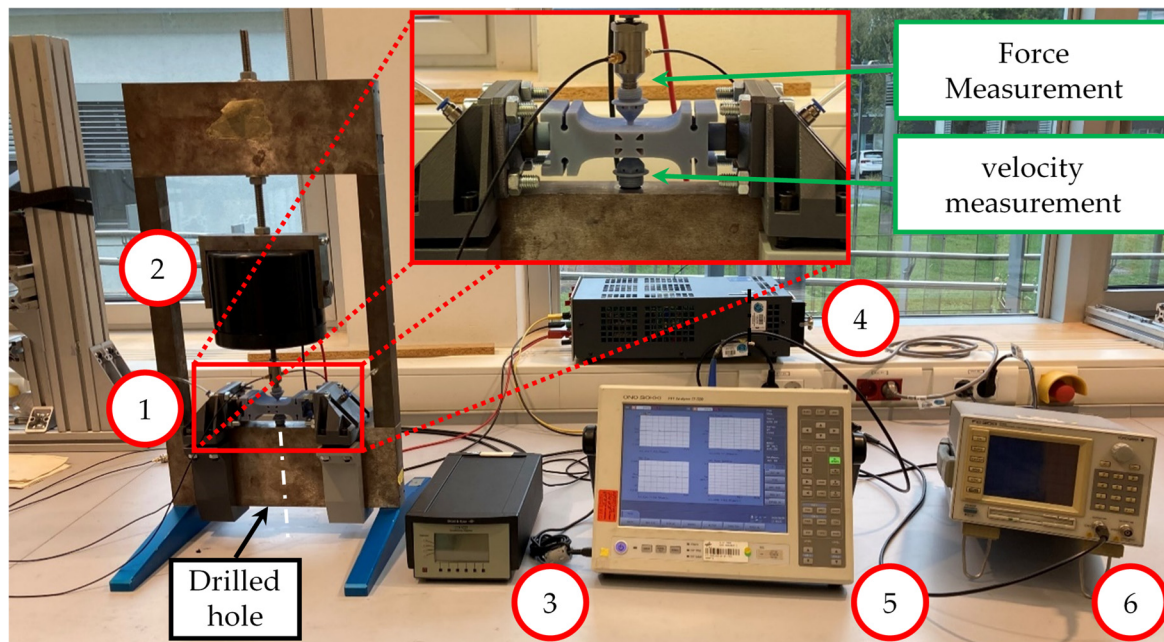


Figure 6. Experimental setup for determining the dynamic properties of the sound introduction unit. (1) Sound introduction unit in the designated clamping device. (2) Shaker (Bruel & Kjaer, Type 4809 Vibration Exciter/Shaker) for exciting the upper mass of the sound introduction unit. The excitation occurs through an impedance sensor from Bruel & Kjaer with the model number "8001". (3) Signal conditioner "Nexus Conditioning Amplifier" from Bruel & Kjaer. (4) Shaker amplifier from Kepco labeled "Bipolar Operational Power Supply/ Amplifier". (5) FFT analyzer from Onosokki labeled CF-7200 for recording the measurement. (6) Signal generator from Yokogawa labeled FG300.

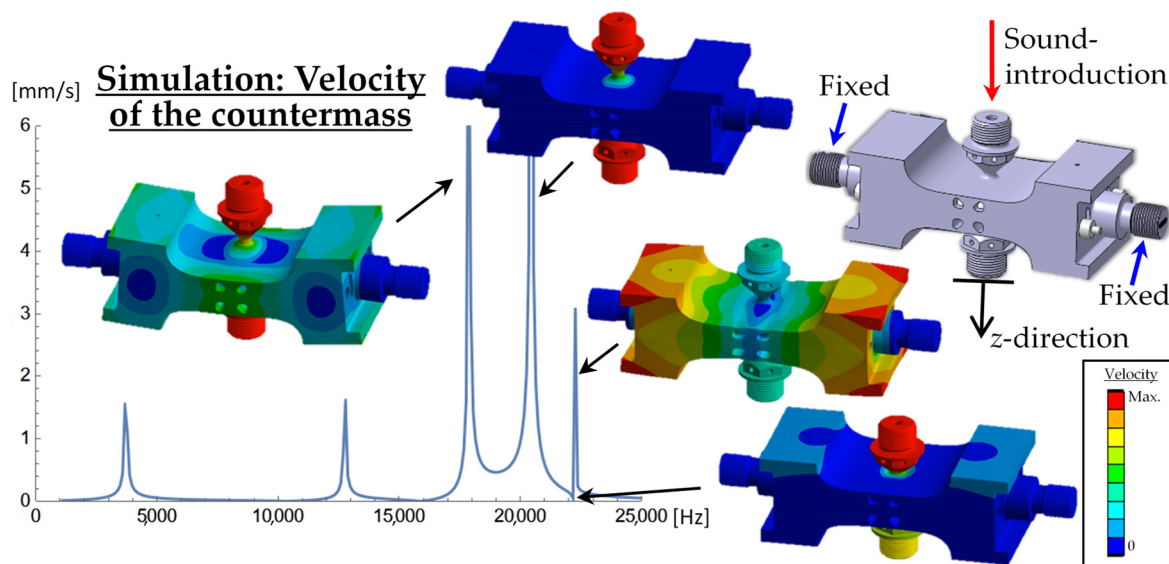


Figure 7. Simulated results of the counter-mass velocity caused by the introduced ultrasound based on a tool made of Toolox44. The deformation of the modes of interest is illustrated d_z.

Thus, the ideal operational frequency falls between the fourth eigenfrequency and the subsequent minimum of the counter-mass speed. The design and manufacturing of the sound introduction unit from the material Toolox44 for integration into the manufacturing process were carried out based on the measurement results of the 3D-printed models.

3. Results and Discussions

Figure 8 shows the final results from the measurement of the dynamic properties of the sound introduction unit made of Toolox44. These measurements were subsequently utilized within the impedance test stand described in Section 2.2. The left graph plots the force detected by the impedance sensor, while the right graph illustrates the resulting speed of the counter-mass. The excitation signal was restricted to the frequency range of 15 kHz to 25 kHz, resulting in the absence of the first two resonances depicted in Figure 7. Within this frequency range, however, the three resonances from the simulation were also observable in the measurement. Discrepancies between the simulation and measurement outcomes can be attributed to the simplified simulation without damping. The critical frequencies are distinctly visible in Figure 8 in the right graph at 17.2 kHz, 18.5 kHz, 19.5 kHz, and 19.8 kHz. Hence, the operational frequency ranges between 18.5 kHz and 19.5 kHz. Installed in the production line (see Figure 9), the tool was driven by the sonotrode without the polymer, which found its frequency of operation at 19.1 kHz, which is within the functional frequency range. This frequency is visually indicated in Figure 8. The peak observed in the graphical representation on the right-hand side of Figure 9 corresponds to the operational frequency, quantified as the velocity of the counter-mass measured with a vibrometer (Polytec GmbH, Type PDV-100 vibrometer). During the experimental trials, the sonotrode control system reported a conversion efficiency of approximately 100% of the total power without any indication of power loss. It is important to consider that this seemingly perfect efficiency may be influenced by the measurement methodology employed at the amplifier stage. Further investigation into the measurement techniques and data acquisition processes would be warranted to fully understand and validate these findings. Subsequent thermal treatment of the cleaning material (250 °C) and polylactic acid (PLA) (220 °C), facilitated by heating elements deployed in the designated boreholes, enables the production of initial semi-finished products. The air-blown cooling holes successfully prevent the temperature transfer to the sonotrode during operation. The ultrasound excitation of polymers within the sound introduction unit is achieved using an amplitude of 50% of the maximum displacement of 30 µm. This results in a power consumption of approximately 50 W for the cleaning material and 94 W for PLA (polylactic acid). Figure 10 presents two graphical representations illustrating variations in displacement from 20% to 50% (blue curves) and corresponding total and net power outputs (orange and black curves), while the operating frequency is around 19,500 Hz.

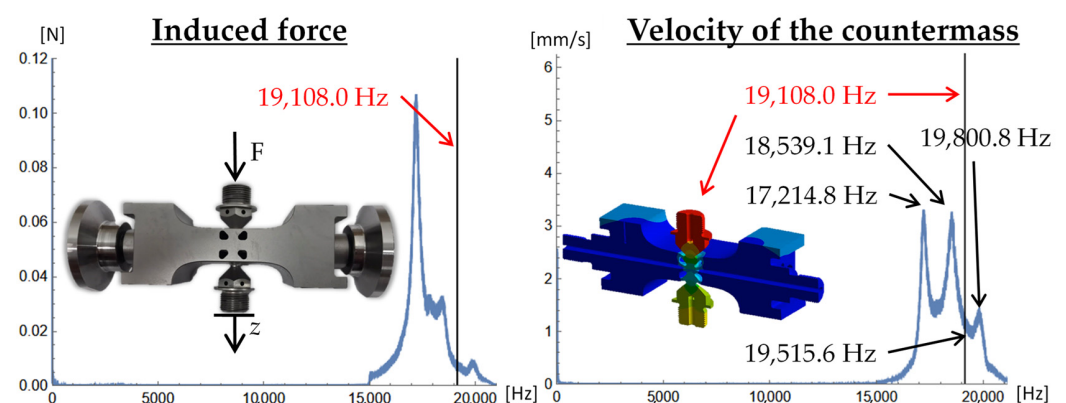


Figure 8. The impedance test stand results illustrating the dynamic properties of the sound introduction unit. The line at 19108 Hz indicates the resonance frequency, which is determined by the sonotrode in its built-in state.

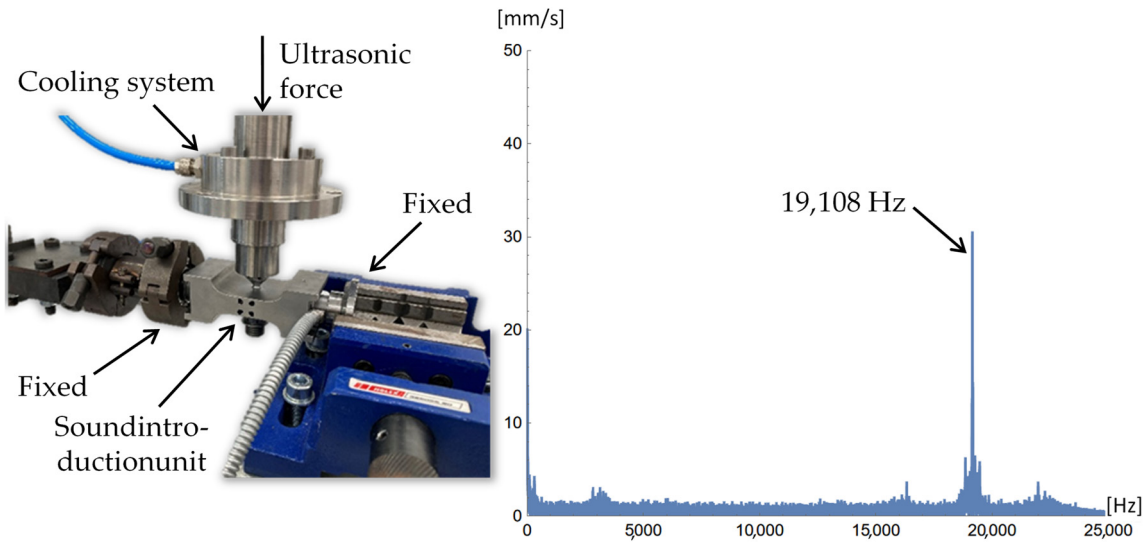


Figure 9. Experimental test setup of the sound-introduction-unit. The ultrasonic transducer locates its frequency of operation at 19108 Hz.

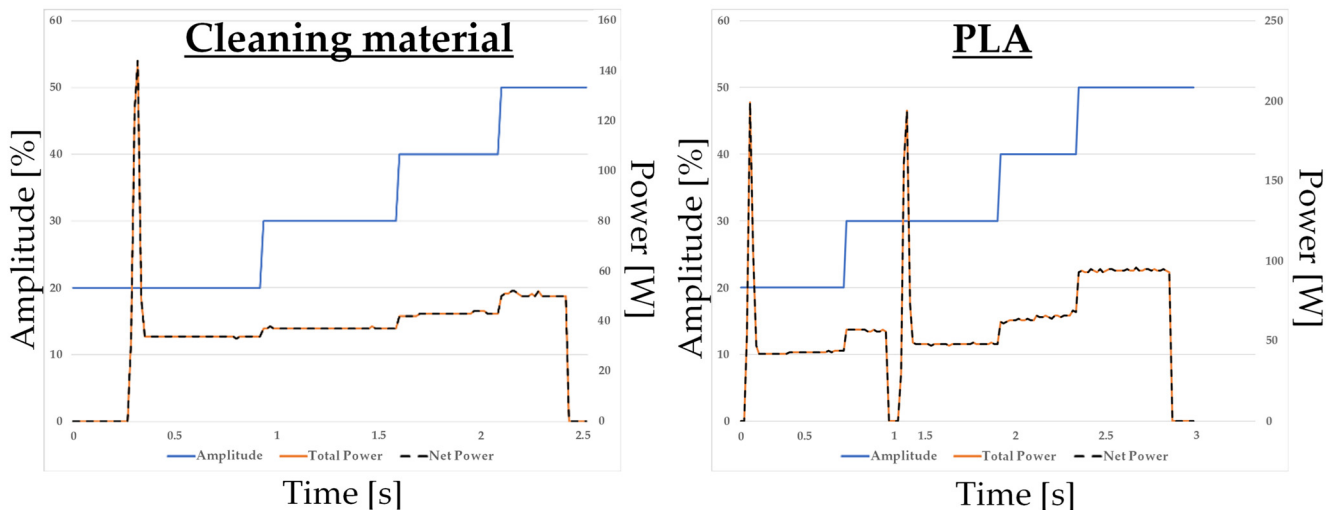


Figure 10. The resulting displacement and subsequent performance of the sonotrode during operation. The cleaning material traverses the sound introduction unit on the left and the PLA on the right.

The change in frequency may be attributed to temperature changes, but these remain within the operational range. Analyzing the trend of achieved power highlights the disappearing stiffness of the sound introduction unit in consideration of the achieved displacement. This relationship indicates inherent power losses within the sonotrode. The sonotrode exhibits significant variations in power consumption when processing different materials, specifically between the cleaning material and the PLA. Notably, doubling the amplitude from 20% to 40% requires a power increase of approximately 27% (from 34 W to 43 W) for the cleaning material and 57% (from 42 W to 66 W) for the PLA. This disparity in energy consumption suggests that the excess power is likely converted into acoustic energy directed toward the PLA. Considering the deformed area within the processing channel, which measures 0.1964 cm^2 (refer to Figure 11 on the right), the calculated power densities at 50% of the maximum amplitude are:

- 254.58 W/cm^2 for the cleaning material at 50 W;
- 478.62 W/cm^2 for PLA at 94 W.

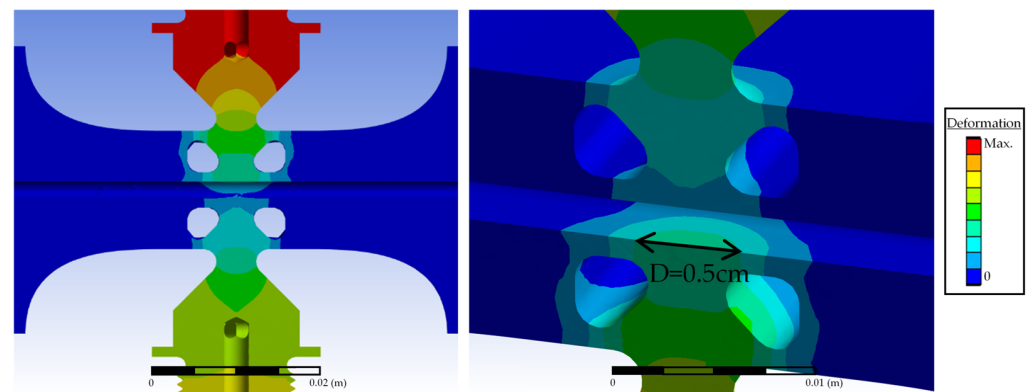


Figure 11. Simulation-determined deformations of the sound introduction unit operating at 19,100 Hz in cross-sectional views. The left-hand image illustrates the side view, elucidating the counter-phase swinging mass responsible for compressing the channel. On the right, the area of the region affected by deformation is depicted. The deformed area inside the channel extends circularly with a diameter of 0.5 cm.

The difference in power consumption between these materials yields a sound power transmission of 44 W, resulting in a power density of 224.03 W/cm².

This power transfer generates additional thermal and mechanical stresses on the polymer, leading to reduced viscosity. The decrease in viscosity manifests as increased flow rates while maintaining temperatures and a constant pressure of 20 bars at the entrance of the sound introduction unit. Table 1 presents the amplitude-dependent flow rate measurements for the PLA, starting with comparative measurements without ultrasonic treatment as the initial state. After each comparative measurement follows a measurement with ultrasonic treatment. Across three measurements, the average flow rate gain is 13.6%, indicating the presence and efficacy of the ultrasonic treatment.

Table 1. The amplitude-dependent flow rate measurements for PLA. The comparative measurements with and without ultrasonic treatment demonstrate the flow rate increase caused by the sound power introduction.

Measurement	0% Ampl. [g/min]	50% Ampl. [g/min]	Gain [%]
1	6.20	7.00	12.9
2	6.30	7.20	14.3
3	6.06	6.88	13.5

4. Conclusions

The purpose of this sound introduction unit was to introduce the sound power produced by the sonotrode into the channel filled with the polymer while keeping the channel closed and decoupling the vibration from the production line. This was achieved by creating a counter-phase motion in opposing masses, which compressed the channel and decoupled holes drilled along and crosswise to the channel. A design guideline was drafted, and the challenges between the simulated design, the modal analysis of the tool, and the behavior in the functional system were given. It was outlined that there was an offset between the designed and final frequencies of the operating mode. However, the measured total power and net power overlaid onto each other, caused by the modal design of the ultrasonic sound introduction unit. This may have interfered with the measurement methodology employed in the amplifier stage. Further investigation into the measurement techniques and data acquisition processes would be warranted to fully understand and validate these findings. However, this study demonstrates significant differences in power

consumption and acoustic energy conversion during the ultrasonic processing of various materials. Specifically, the sonotrode exhibited substantial variations in power usage when processing the cleaning material versus polylactic acid (PLA). These findings suggest that the excess power is likely converted into acoustic energy directed toward the PLA, resulting in increased thermal and mechanical stresses on the polymer. The calculated power densities at 50% of the maximum amplitude revealed substantial differences between the materials, with the PLA exhibiting higher values (478.62 W/cm² at 94 W) compared with the cleaning material (254.58 W/cm² at 50 W). This disparity led to sound power transmission directly to the PLA of 44 W, generating a power density of at least 224.03 W/cm². These observations are supported by the experimental measurements showing average flow rate gains of 13.6% across three measurements after implementing the ultrasonic treatment while keeping the temperatures (PLA: 220 °C; cleaning material: 250 °C) and the pressure at the entrance of the sound introduction unit constant (20 bars). The conducted research demonstrated the functional ability impressively. A tool was designed to decouple the movement of the tool itself from the areas of the heating element and sensor integration, as well as the sealing to the rest of the machine.

Author Contributions: Conceptualization, M.R.A.S. and J.-U.R.S.; methodology, M.R.A.S.; software, M.R.A.S.; validation, M.R.A.S. and J.-U.R.S.; formal analysis, M.R.A.S.; investigation, M.R.A.S. and J.-U.R.S.; resources, M.T. and H.P.M.; data curation, M.R.A.S.; writing—original draft preparation, M.R.A.S.; writing—review and editing, J.-U.R.S.; visualization, M.R.A.S.; supervision, H.P.M. and M.T.; project administration, J.-U.R.S. and M.R.A.S.; funding acquisition, M.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Helmholtz Association [project name: *SchallFTP*] (grant number: KA-TVP-06).

Data Availability Statement: The data presented in this study are available in this article.

Acknowledgments: The authors would like to thank the Helmholtz Association for supporting these investigations in a validation project. A special thanks goes to Ensinger GmbH for sponsoring this project by being an external industrial advisor. Our thanks also go to the German Aerospace Center (DLR) for providing their facilities and infrastructure to support our experimental activities.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Ma, P.-C.; Siddiqui, N.A.; Marom, G.; Kim, J.-K. Dispersion and functionalization of carbon nanotubes for polymer-based nanocomposites: A review. *Compos. Part A Appl. Sci. Manuf.* **2010**, *41*, 1345–1367. [\[CrossRef\]](#)
2. McNally, T.; Pötschke, P. Polymer-Carbon Nanotube Composites: Preparation, Properties and Applications. In *Polymer-Carbon Nanotube Composites*; Woodhead Publishing: Cambridge, UK, 2011; ISBN 9781845697617. [\[CrossRef\]](#)
3. Isayev, A.I.; Kumar, R.; Lewis, T.M. Ultrasound assisted twin screw extrusion of polymer-nanocomposites containing carbon nanotubes. *Polymer* **2009**, *50*, 250–260. [\[CrossRef\]](#)
4. Zhong, J.; Isayev, A.I. Properties of Polyetherimide/Graphite Composites Prepared Using Ultrasonic Twin-Screw Extrusion. *J. Appl. Polym. Sci.* **2014**, *132*. [\[CrossRef\]](#)
5. Gorga, R.E.; Cohen, R.E. Toughness enhancements in poly(methyl methacrylate) by addition of oriented multiwall carbon nanotubes. *J. Polym. Sci. Part B Polym. Phys.* **2004**, *42*, 2690–2702. [\[CrossRef\]](#)
6. Díez-Pascual, A.M.; Naffakh, M.; Marco, C.; Ellis, G.; Gómez-Fatou, M.A. High-performance nanocomposites based on polyetherketones. *Prog. Mater. Sci.* **2012**, *57*, 1106–1190. [\[CrossRef\]](#)
7. Xu, X.; Wie, K.; Mei, M.; Li, M.; Yang, X. An ultrasound-assisted resin transfer molding to improve the impregnation and dual/scale flow for carbon fiber reinforced resin composites. *Compos. Sci. Technol.* **2024**, *255*, 110710. [\[CrossRef\]](#)
8. Horrocks, A.R.; Kandola, B.; Milnes, G.J.; Sitpalan, A.; Hadimani, R.L. The potential for ultrasound to improve nanoparticle dispersion and increase flame resistance in fibre-forming polymers. *Polym. Degrad. Stab.* **2012**, *97*, 2511–2523. [\[CrossRef\]](#)
9. Xia, H.; Wang, Q.; Qiu, G. Polymer-Encapsulated Carbon Nanotubes Prepared through Ultrasonically Initiated In Situ Emulsion Polymerization. *Chem. Mater.* **2003**, *15*, 3879–3886. [\[CrossRef\]](#)

10. Tzanakis, I.; Khavari, M.; Titze, M.; Eskin, D.G. Cavitation in thermoplastic melts: New insights into ultrasound-assisted fibre-impregnation. *Compos. Part B Eng.* **2022**, *229*, 109480. [[CrossRef](#)]
11. Zhau, B.; Qiang, Y.; Wu, W.; Jiang, B. Turning Power Ultrasound for Enhanced Performance of Thermoplastics Micro-Injection Molding: Principles, Methods, and Performances. *Polymers* **2021**, *13*, 2877. [[CrossRef](#)]
12. Qiao, J.; Li, Y.; Li, L. Ultrasound-assisted 3D printing of continuous fiber-reinforced thermoplastic (FRTP) composites. *Addit. Manuf.* **2019**, *30*, 100926. [[CrossRef](#)]
13. Chen, J.; Chen, Y.; Li, H.; Lai, S.-Y.; Jow, J. Physical and chemical effects of ultrasound vibration on polymer melt in extrusion. *Ultrason. Sonochemistry* **2010**, *17*, 66–71. [[CrossRef](#)]
14. Khamsehnezhad, A. The Effects of Ultrasonic Waves Application During Extrusion on the Processing Parameters and the Properties of Polyethylene. Ph.D. Thesis, Brunel University London, Uxbridge, UK, 2014. Available online: <http://bura.brunel.ac.uk/handle/2438/13956> (accessed on 30 January 2025).
15. Zhong, J.; Isayev, A.I. Ultrasonic Treatment of PP/CNT Composites During Twin-Screw Extrusion: Effect of Screw Configuration. *Polym. Compos.* **2017**, *38*, 2695–2706. [[CrossRef](#)]
16. Kroos, K.; Diniz, S.; Bachmann, J.; Chakraborty, S.; Kühnast, F.; Schmidt, J.-U.R.; Opitz, S. Filaments For Additive Manufacturing Reinforced with Carbon Fibers From Waste Stream. In Proceedings of the 21st European Conference on Composite Materials, Nantes, France, 2–5 July 2024; Volume 7. [[CrossRef](#)]
17. Titze, M. Verfahren und Vorrichtung zum Imprägnieren eines Faserbündels sowie Verfahren und Anlage zur Herstellung Einer Dreidimensionalen Struktur. Patent: DE 10 2019 106 355.8, 2020.
18. Hiller, T. Schwingungsverhalten von Abgasanlagen mit Entkoppelelementen. Ph.D. Thesis, Friedrich-Alexander-Universität, Erlangen, Germany, 2023.
19. Sophianopoulos, D.S. The effect of joint flexibility on the free elastic vibration characteristics of steel plane frames. *J. Constr. Steel Res.* **2003**, *59*, 995–1008. [[CrossRef](#)]
20. Seidel, M. Auslegung von Hybriddtürmen für Windenergieanlagen- Lastermittlung und Nachweis der Ermüdungsfestigkeit am Beispiel einer 3,6-MW-WEA mit 100m Rotordurchmesser. *Beton Und Stahlbetonbau* **2002**, *97*, 564–575. [[CrossRef](#)]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.