MHz - Tomoscopy

D3.1

Portable sample setup for cavitation peening experiments

Project information

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Duration	42 months
Website	https://tomoscopy.eu/

Deliverable information

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Document information

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Abstract

This report provides an update on D3.1 related to Task 3.1, which focuses on developing a portable sample environment for cavitation peening experiments using multi-projection MHz-TOMOSCOPY. The deliverable, D3.1, was successfully completed in M23 and is now ready to be used for the forthcoming experiments on cavitation peening.

Executive Summary

In Task 3.1, the sample setup was designed based on the technical parameters from Task 1.1, building upon a previous design by Hitoshi Soyama (Tohoku University). This setup involves a water tank, a pump, pressure transmitters, Venturi tubes, a flowmeter, and a valve. Importantly, the system interfaces with a LabVIEW control system which enables remote operation and adjustment of the flow conditions, essential for experiments at an X-ray facility. The system was also successfully integrated into the MHz-TOMOSCOPY prototype diagnostic at European XFEL. The following sections of this report present details of the setup and the integration with the MHz-TOMOSCOPY diagnostic at the SPB/SFX instrument at European XFEL.

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1. Technical requirements

This section lists the main specifications of the sample setup required for the MHz-TOMOSCOPY prototype. According to Task 1.1, the sample setup must be fully automated, as it will be placed inside the beam hutch that needs to be evacuated during experiments. The setup should enable diagnostic access to the sample environment with limited X-ray attenuation or introduction of phase artefacts. Additionally, the setup should facilitate the replacement of the Venturi reactor with minimal realignments.

2. Sample setup

The experimental setup developed in Task 3.1 for cavitation peening experiments using the MHz-TOMOSCOPY prototype comprises a feeding line, sensors, and Venturi reactors. Figure 1 the sample environment involving the Venturi reactor and kinematic plates. These plates were designed to minimize alignment errors when changing the Venturi reactors, with an opening at the centre allowing the transmission of the X-rays with minimum beam interference. The sample environment is connected to the sample setup as shown in Figure 2. The sample setup, which includes a water tank connected to a pump that delivers fluid into the sample environment. The static pressure on the inlet and outlet of the sample environment is monitored using analogue pressure indicators and measured by utilizing pressure transmitters. A control valve is used downstream of the sample environment to adjust the back pressure, aiming to control the cavitation number for a given flow rate. Details of the sensors are summarized in Table 1.

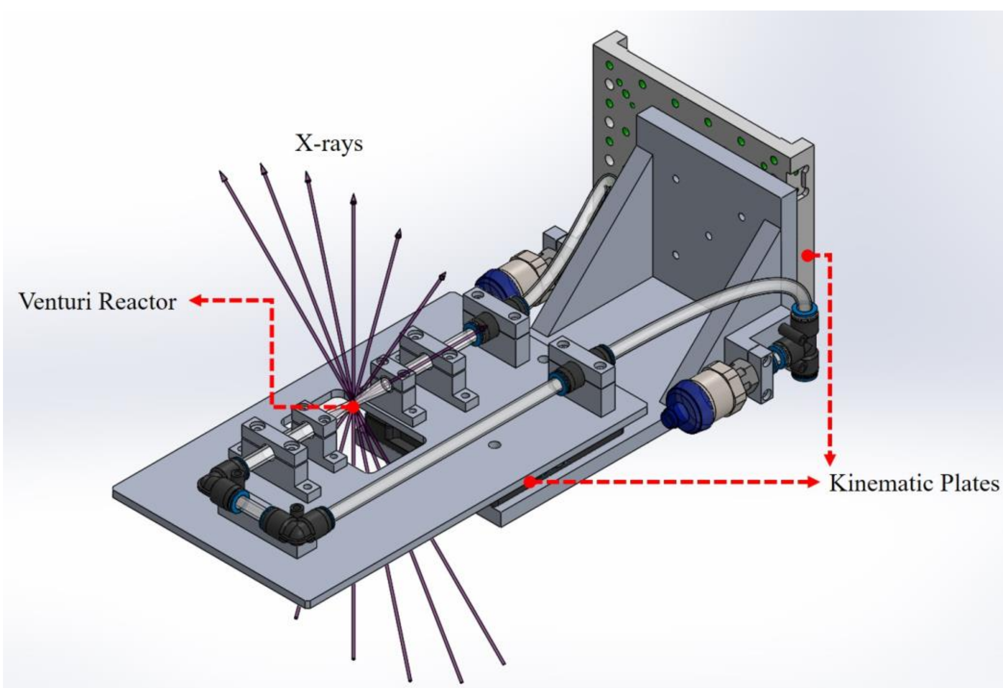

Fig. 1. CAD figure of the sample environment.

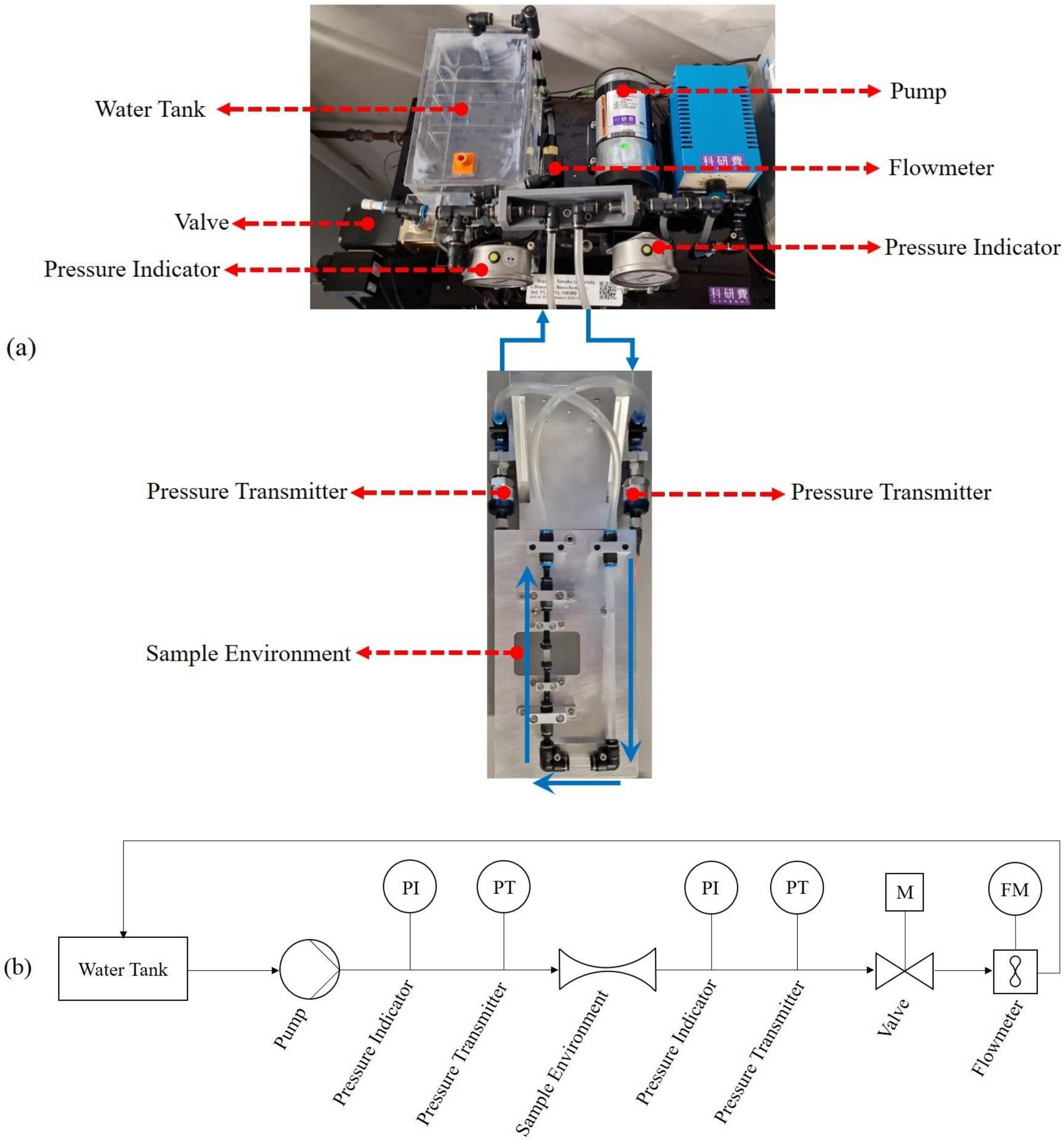

Fig. 2 (a) top view and (b) schematic view of the sample setup.

Table 1. The detailed information on the sensors

Sensors	Type	Range	Accuracy
Pressure transmitter	Gauge	0-4 bar	±5% Full scale
Valve	Proportional	0-100 %	1%
Flowmeter	Turbine	1-25 L/min	±2

3. Venturi reactor

The experimental setup is planned to be used to perform experiments in Task 3.4, with the results obtained used to validate the numerical simulations performed in Task 3.2. Therefore, it was essential to identify the precise operating conditions of the experiments and maintain a well-controlled manufacturing process to produce optically accessible Venturi tubes. Considering the miniature dimensions of the Venturi tubes, approximately 1 mm in size, the tolerance of conventional methods to manufacture a Venturi using glass or polycarbonate is roughly ±0.1 mm. This level of tolerance makes it challenging to accurately reproduce the same conditions in experiments and to then model the same with numerical simulations. To address this issue, an advanced 3D printer at the University of Oxford was used to print the Venturi reactors from clear resin. This manufacturing process has a tolerance of ±50 μm, which is on the order of the computational grid used in CFD simulations. Additionally, this method allows for the manufacturing of Venturi tubes with very thin walls, making them compatible with the X-ray laser energy available at European XFEL. In Task 3.1, various Venturi reactors were printed and tested to examine the effects of Venturi specifications on the cavitation regime and implosion pressure of cavities, which are crucial parameters for cavitation peening. Figure 3 illustrates the schematic view of some of the printed Venturi reactors to specifically study the effects of the divergence angle of Venturi (Figures 3 (a) and (b)), throat length (Figure 3 (c)), turbulent level (Figure 3 (d)), and swirl intensity (Figure 3 (e)) on cavitation. Such investigations led to the selection of the most effective Venturi reactor configuration for cavitation peening. Figure 4 shows flow cavitation inside one of the printed Venturi tubes. Here, shadowgraphy was used to image the cavitation, with the darker areas indicating the regions of cavitation.

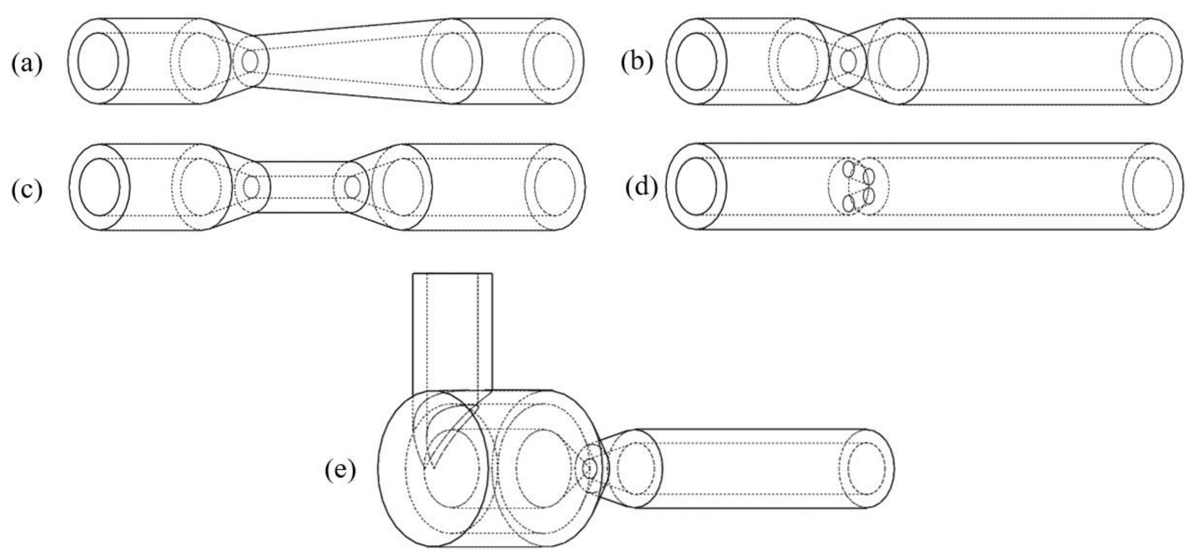

Fig. 3. Schematic view of the printed Venturi reactors, designed to investigate the effect of varying divergence angle (a and b), throat length (c), turbulence level (d), and swirl intensity (e) on cavitation.

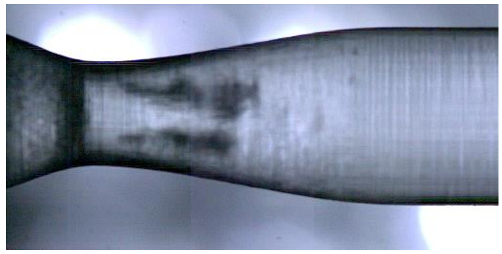

Fig. 4. Cavitating flow inside a printed Venturi reactor. The vertical (circumferential) features are due to the SLA 3D printing process, with the darker region at centre due to scattering of light off the cavitation.

4. Integration with MHz-TOMOSCOPY instrument

The sample setup was integrated into the MHz-TOMOSCOPY prototype by mounting the sample environment on a railed breadboard, which is controlled by a motor to precisely position the sample in front of the X-ray beam. Figure 5 shows the integrated sample environment with the MHz-TOMOSCOPY instrument.

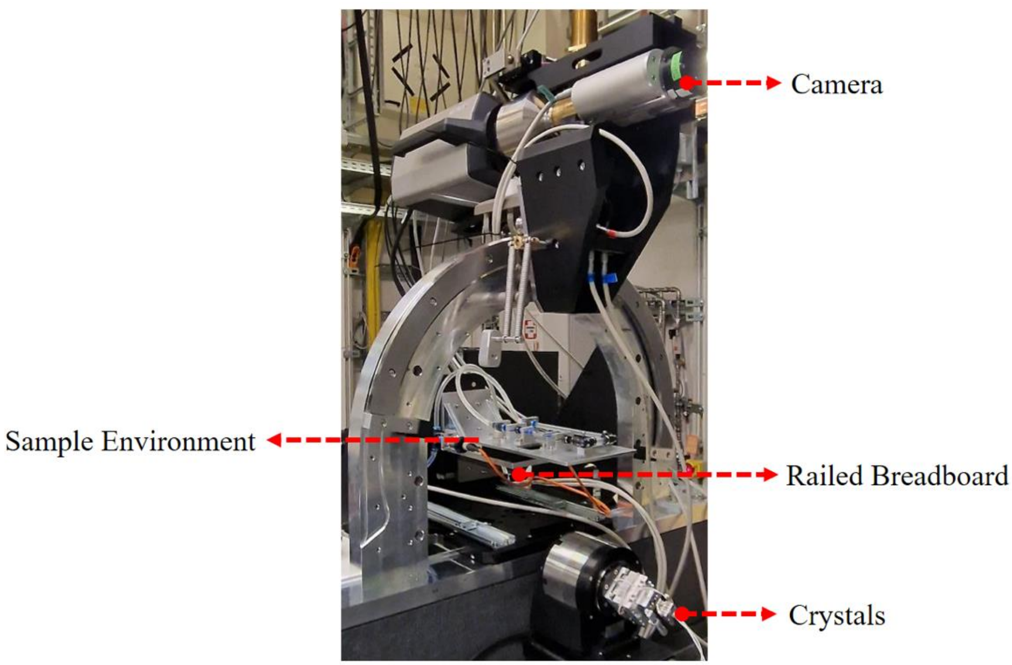

Fig. 5. Integrated sample environment with the MHz-TOMOSCOPY instrument

5. LabVIEW control system

The sensors used in the sample setup were connected to a control unit, which comprises a junction box (shown in Figure 6) and a computer running Laboratory

Virtual Instrument Engineering Workbench (LabVIEW). The junction box distributes the main electrical power to the sensors, including the pump (PMP), flowmeter (FM), control valve (CV), and pressure transmitters located at the inlet and outlet of the Venturi tubes (PTi and PTe, respectively), based on their working voltages. Moreover, the junction box houses a multifunction data acquisition device (NI USB-6003) for sensor control.

Fig. 6. Front view of the junction box.

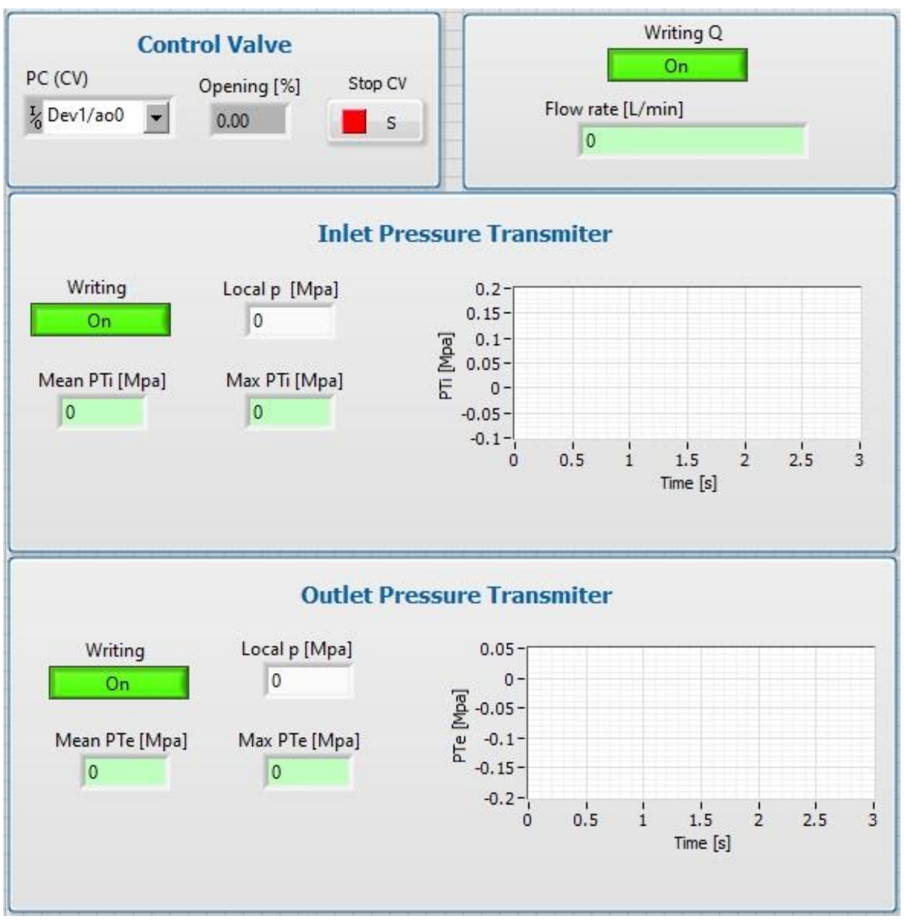

Fig. 7. Snapshot of the control system in LabVIEW.

Figure 7 shows a snapshot of the front panel of the control program developed in LabVIEW. This program regulates the opening percentage of the control valve by sending an analogue voltage signal to the valve. The volume flow rate measured by the turbine flowmeter is sent to the NI USB device as an analogue voltage signal, while the pressure transmitters communicate with the control unit by sending analogue current signals. The program also displays the instantaneous flow rate in litre per minute, as well as the averaged and maximum values of the upstream and downstream flow pressure on the front panel. Temporal pressure signals are also plotted on the front panel to allow real-time system monitoring. Additionally, the program records the measured signals to a hard drive for further analysis.