



## **GO-VIKING**

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### **Single-phase GOKSTAD experiments and benchmark setup**

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Summary

Description of the GOKSTAD facility and experimental data.

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# D3.3 - Single-phase GOKSTAD experiments and benchmark setup

Description of the GOKSTAD facility and experimental data

Version N°4  
June / 2024



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## Abbreviations and Acronyms

| Acronym   | description                                                         |
|-----------|---------------------------------------------------------------------|
| WP        | Work package                                                        |
| GO-VIKING | Gathering expertise On Vibration ImpaKt In Nuclear power Generation |

## Summary

The GOKSTAD (**GO-VIKING** experimental **SeTup** to **Assess** FIV by cross-flow in tube bunDles) facility is a new water loop experiment designed and built at the von Karman Institute to study flow-induced vibration (FIV) of circular rods in a square lattice shape in a cross-flow single phase. This deliverable describes the main features of this new facility.

## Keywords

Experimental facility, FIV, cross-flow, GOKSTAD, water model, single phase, fluid-structure interaction, PIV

# 1. Test facility

## 1.1 Description of the GOKSTAD facility

The facility is a closed water loop divided into three sections:

The first section is the flow regulation section, composed of the pump, a flow meter, and a regulation valve.

The second section is the test section composed of two divergent/convergent composed of a pair of round-to-rectangle, a small and a long rectangular channel upstream of the test section to develop the flow, the test section itself, and another rectangular channel downstream the test section.

The third part of the facility is the return section, composed only of piping and plumbing accessories.

All the facility and its main components are made of stainless steel, except the cylinder tubes, which are made of Plexiglass (PMMA). The first and third sections are in DN100 (Dext=114.3mm with 2 mm thickness), and the test section is a rectangular channel of 200x172.8mm internal size. The inlet rectangular channel is 2040mm long and is divided into two parts. The first minor part can be replaced or adapted if the flow is not fully developed, by adding a flow straightener. This decision will be made after the first PIV measurements. The test section is 520mm long, such as the outlet rectangular channel.

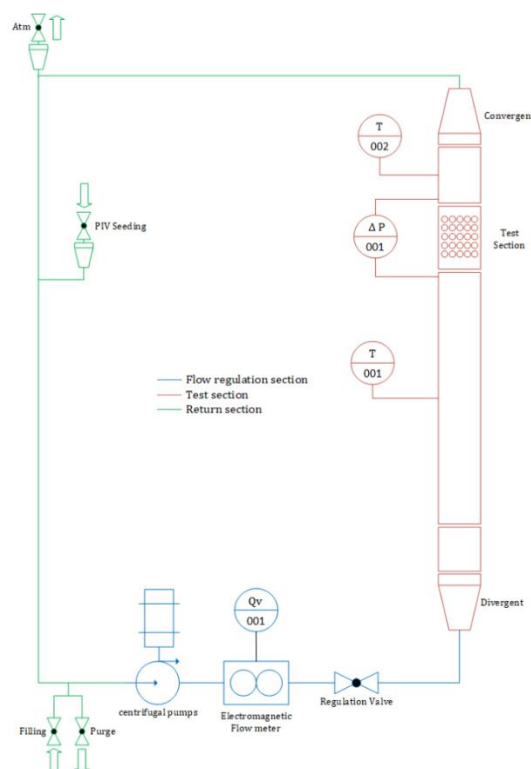


Figure 1: Piping and instrumentation diagram of GOKSTAD

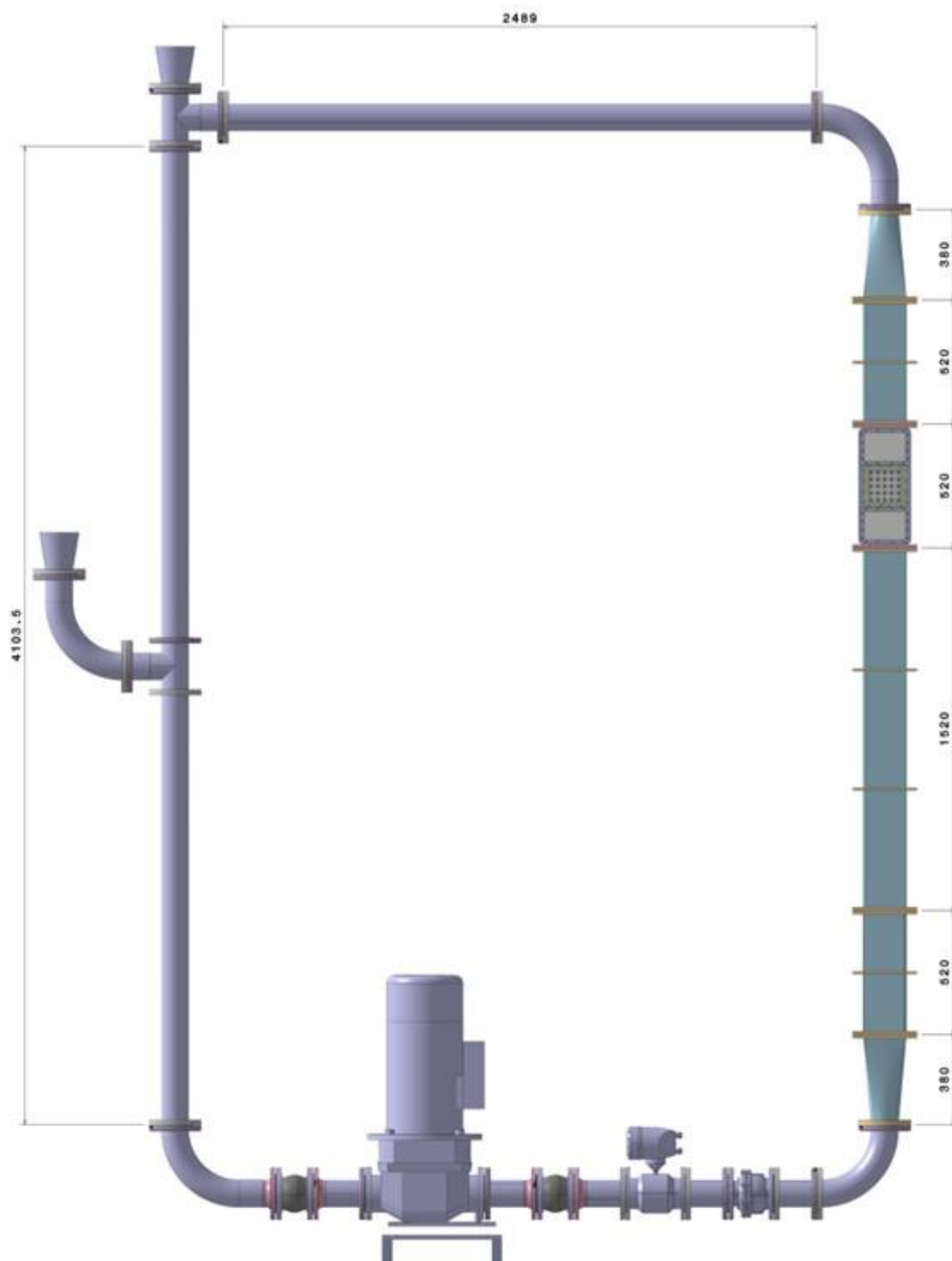


**Figure 2: GOKSTAD test loop - overall dimensions**

The facility is surrounded and carried by a Bosch Profiles structure. A two-meter-high platform is placed around the test section, which can be reached with a dedicated staircase.



**Figure 3: Test section with inlet and outlet channels**



**Figure 4: Structure and stairs**

The pump Atmos GIGA-I 100/140-18,5/2-L4 has been chosen to reach a volumetric flow of  $\pm 187 \text{ m}^3/\text{h}$  corresponding to a flow speed of 1,5 m/s inside the rectangular channel.

The flow rate is adjusted using a variator Wilo-EFC15 3x380-480V 50/60Hz.



**Figure 5: Pump and variator**

The pump is mounted on its support with three vibration isolators, model M50 B.

The rigid line is also isolated from the pump's vibrations by two compact compensators DN100, (reference KOMFLK100) to isolate the facility from the pump vibrations.

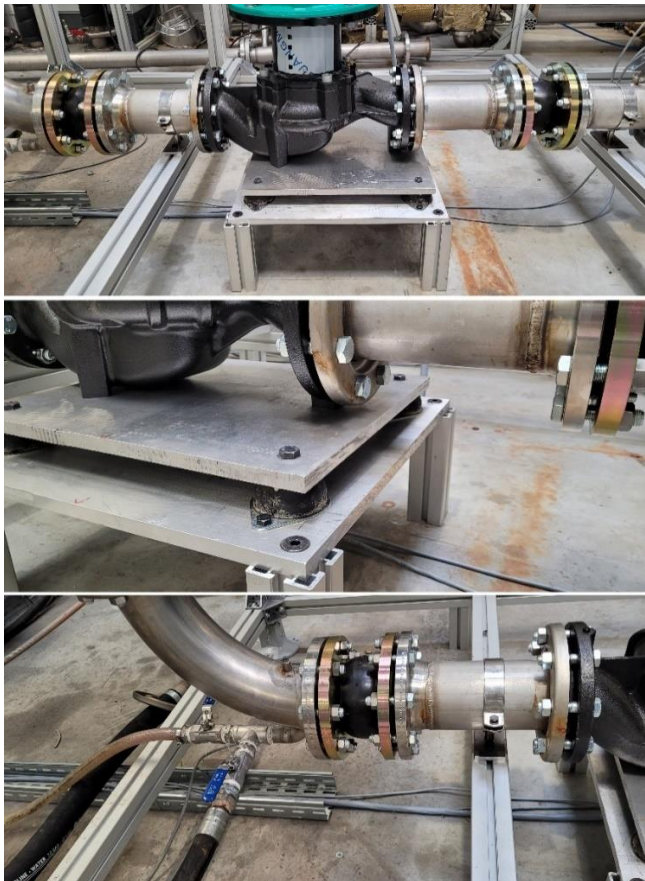


**Figure 6: Pump mounting and vibration isolators**

The electromagnetic flow meter “Waterflux 3000” and its measurement converter IFC 300 measure the volumetric flow. This converter can acquire the volumetric flow via a 4-20mA signal. We can regulate and adjust the flow to a desired target thanks to a LabVIEW program, which contains a regulation loop between the flow meter input and the output 0-10V to the

pump variator. The working temperature range is -5 to 70°C and promises valid measurements for the experiments with an uncertainty of  $\pm 0.2\%$  of the mass flow rate.

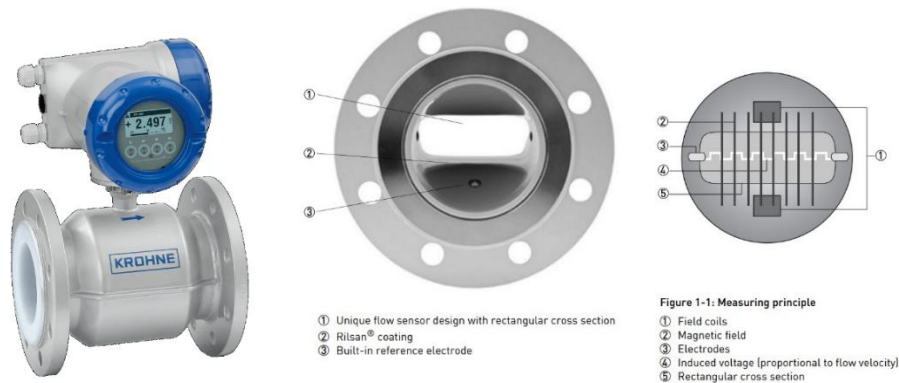


**Figure 7: Electromagnetic flow meter Waterflux 3000 + IFC 300**

A differential pressure sensor measures the pressure drop of the test section. Each side of the differential pressure sensor is connected to four pressure taps, one on each channel side. Two insulated thermocouples of type T are placed before and after the test section to measure the temperature of the water. They are placed further away not to perturbate the flow and the differential pressure sensor.

## 1.2 Design of the test section

The test section is a rectangular stainless-steel channel of 200x172.8mm internal size. It contains a network of plexiglass cylinders with a diameter of 20mm and a length of 200mm. Below is a representation of the network:

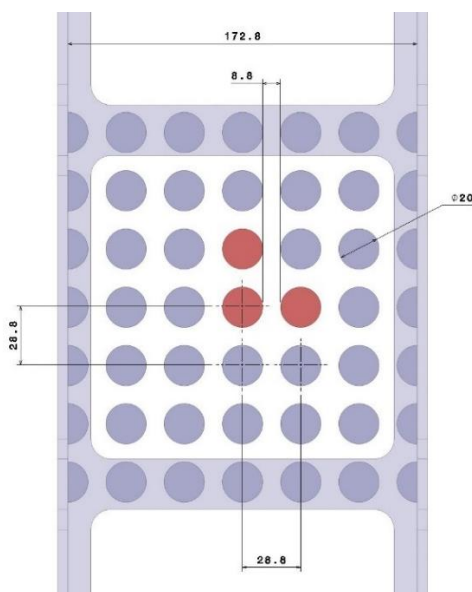


**Figure 8: Bundle configuration**

This bundle is composed of seven rows of five plus two half cylinders. In the two directions, the center-to-center distance between two cylinders is 28.8mm ( $= 1.44 \times \varnothing$  cylinder).

There are three plexiglass windows for optical access on each side of the channel. The blue lines that are shown on Figure 9 will be used for the pressure measurements (pressure losses of the bundle).

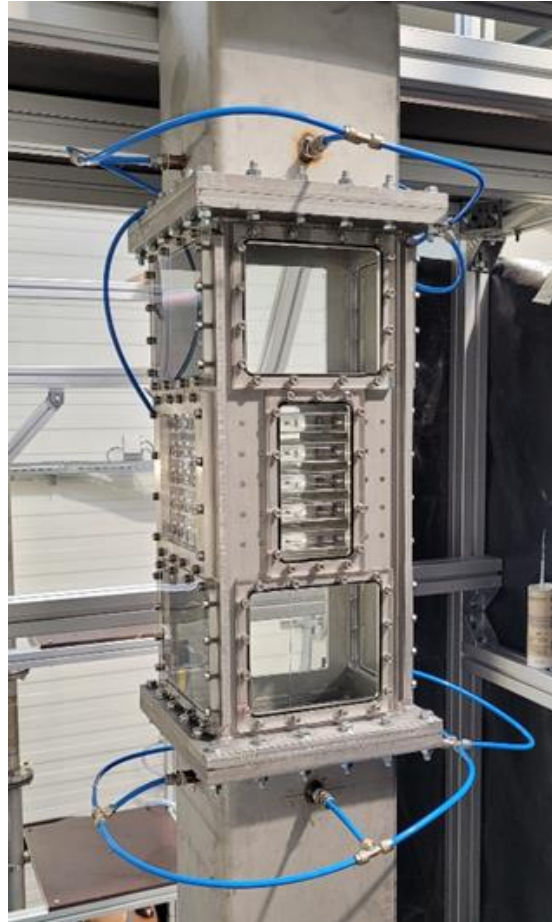


**Figure 9: Test section – optical access and pressure tubes (in blue)**

The test section has three different configurations:

- Configuration n°1: rigid mode – no instrumentation of the tube bundle
- Configuration n°2: vibration mode - FIV
- Configuration n°3: rigid mode with force measurement

### 1.2.1 Configuration n°1: rigid mode – no instrumentation of the tube , bundle

In this configuration, the cylinders made from a full rod in Plexiglass (PMMA), are fixed without any sensors mounted on them. This case is used to characterize the inlet and outlet regime of the flow (velocity and turbulence intensity) in terms of the volumetric mass flow.

### 1.2.2 Configuration n°2: vibration mode - FIV

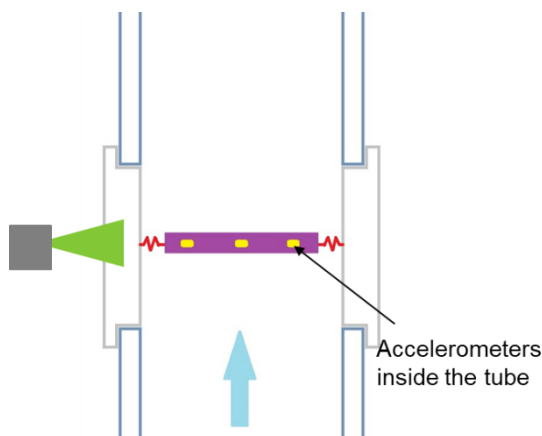


Figure 10: configuration 2

This configuration aims to study the induced vibrations by the water flow on three cylinders in the middle of the network (see red cylinders on the Figure 8: Bundle ). The two extremities are attached to a “spring system” allowing the cylinders to vibrate in two directions.

Different springs and configurations are tested to select the best arrangement. The design for the final configuration is still ongoing to define the best spring arrangement. Once the design is finalized, which will be before the start of the third measurement campaign, see below, the material and structural parameters of the cylinder will be shared with all partners involved in the task.

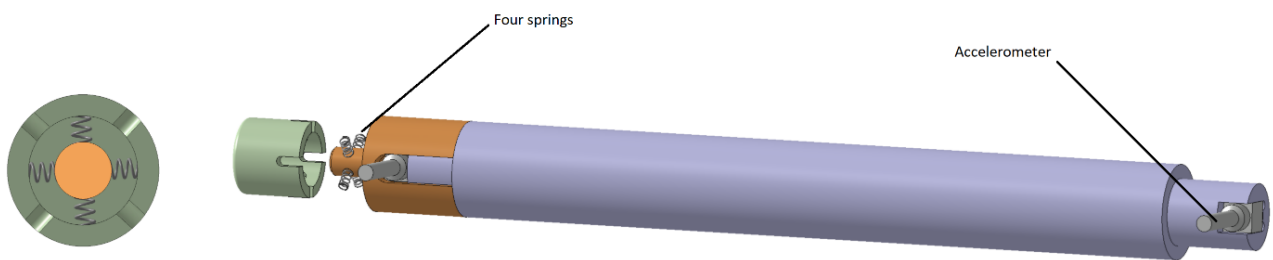
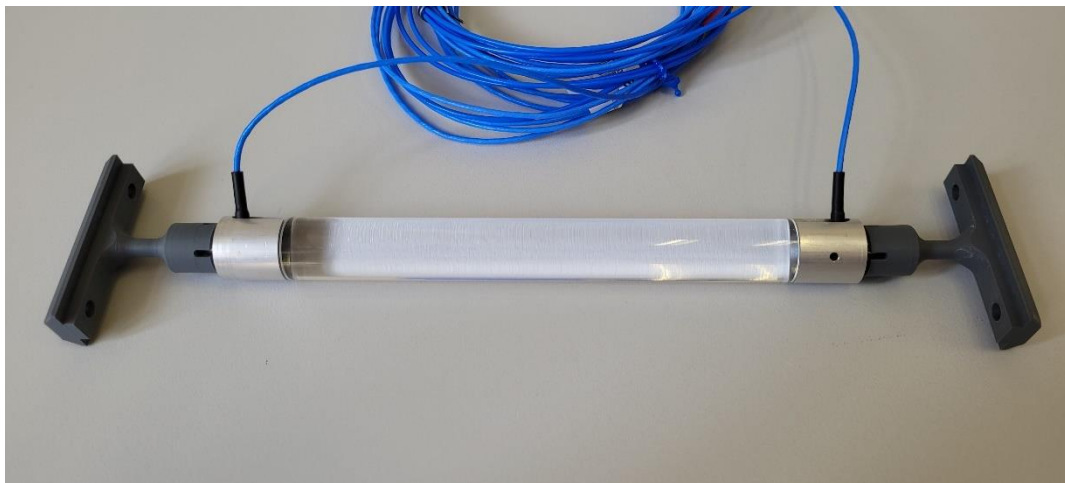
| Springs  |       |       |               |
|----------|-------|-------|---------------|
| Name     | 20260 | 20610 | C00880120190S |
| d [mm]   | 0.2   | 0.32  | 0.30          |
| De [mm]  | 2.2   | 1.92  | 2.24          |
| Di [mm]  | 1.8   | 1.28  | 1.64          |
| L0 [mm]  | 5.9   | 4.40  | 4.83          |
| R [N/mm] | 0.32  | 4.17  | 2.12          |

**Table 1: Springs examples**

Two accelerometers 356A03 are placed at both extremities of only the central cylinder. Only one cylinder will be instrumented with accelerometers. The accelerometers are placed at the edge of the 200 mm long cylinders (Figure 11). The distance from center-to-center of the accelerometers is equal to 192 mm.

The measurements with the accelerometers will be complementary to the displacement measurements that will be made using a high-speed camera (see chapter 2.1.2).

These accelerometers are 3-axis with a sensitivity of  $1.02 \text{ mV}/(\text{m/s}^2)$ . They have  $1/4''$  side which is small enough to be able to insert them into the cylinder but also to have a not too heavy weight (1g).

**Figure 11: Vibrating cylinder(sketch)****Figure 12: Instrumented vibrating cylinder – ready for preliminary tests**

### 1.2.3 Configuration n°3: rigid mode with force measurement

For the last configuration, we replace the same three cylinders in the middle of the network (see red cylinders on the Figure 8: Bundle ) with cylinders (strain gauges) on which force sensors are placed. The load cells will measure the forces separately in the two directions, perpendicular to the cylinder.

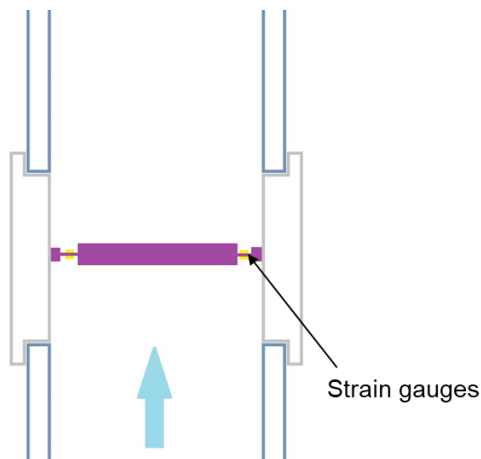


Figure 13: configuration 3

## 1.3 Acquisition and control

A LabView program has been created to acquire all the sensors and regulate the flow. A cDAQ 9178, chassis 8 slots from National Instrument, is connected to the acquisition computer by USB. This chassis includes several National Instrument cards to acquire and control all the instruments and sensors. The 4-20mA signal from the volumetric flow meter is acquired through a NI card 9203 and control the pump with a 0-10V output NI card 9263. The pressure sensor is acquired with a NI card 9215, and the thermocouples with a NI card 9212. The two accelerometers for the vibration system are acquired through a NI card 9234.



Figure 14: NI chassis and cards

## 2. Measurements

### 2.1 Optical measurements

#### 2.1.1 PIV (flow field measurements)

The main goal of the flow field measurements in this project is to provide quantitative data that clarifies the effects of the vibration system on the flow field across the test section. Additionally, these measurements aim to contribute to the 2D spatially resolved boundary conditions at both the inlet and outlet of the test section for numerical studies. Therefore, the selection of measurement techniques is of utmost importance.

The current experimental configuration discourages the use of intrusive measurement methods such as hot wire anemometry and pitot probes. This is primarily because the small size of the rods in the examined geometry would be affected by these probes, changing the original flow path and resulting in inaccurate vibration characterization. Instead, non-intrusive techniques such as Laser Doppler Velocimetry (LDV) and Particle Image Velocimetry (PIV) are preferred as they do not disrupt the original flow field. Due to the requirement for spatially resolved data and the specific geometry under investigation, PIV has been chosen for use.

PIV involves recording the movement of seeding particles that follow the flow. The velocity of these particles is determined by measuring their displacement over a specific time interval. In the experiments, a laser sheet illuminates the particles within a plane in the test section. The illuminated particles' positions are recorded using a CCD camera. The PIV configuration that is designed for the present study is shown in Figure 15: PIV configuration.

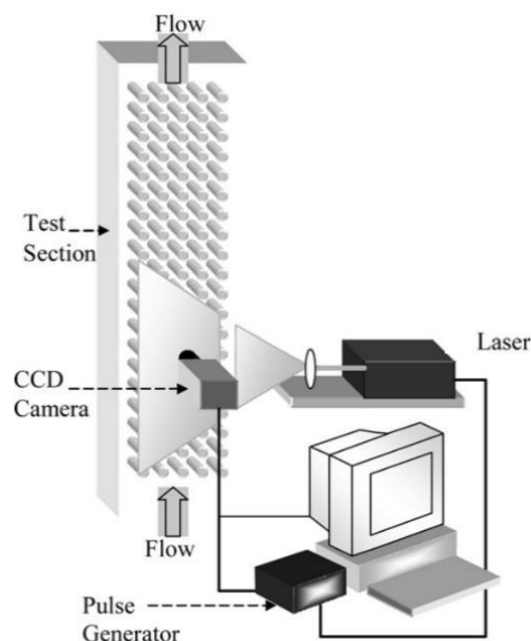


Figure 15: PIV configuration

We will perform PIV measurements using a vertical Laser sheet as illustrated in Figure 15. In the first measurement series, the PIV plane will be located upstream of the cylinder bundle to characterize the inflow boundary conditions.

In this configuration, optical access for the laser sheet and camera is essential in the test section. This allows the laser to illuminate the particles in the flow, enabling the cameras to record their positions. In the present study, these accesses are achieved by constructing transparent rectangular plexiglass optical windows in the regions of interest. Additionally, the rods are made of Plexiglass to allow the laser sheet to pass through the desired plane. The refractive index of the working fluid is similar to that of the test section, minimizing laser refractions from the rods around the investigated plane. This ensures uniform laser intensity and, consequently, uniformly illuminated particles in the field of view. This study will use water as the working fluid due to its operational simplicity.

In this study, a dual cavity solid state Nd:YAG laser with maximum output energy of 200mJ and a wavelength of 532nm will be used as laser source to generate the laser beam. The optical lenses will then be placed after the laser head to form a laser sheet with an average thickness of around 1.5 mm. The laser produces two pulses that create the same laser sheet, separated by a set time interval  $\Delta t$ .

The camera is synchronized with the laser pulses to capture images of the particles exactly when the laser pulses. The camera's field of view includes three vibrating and six nearby rods. A telecentric lens (0.088X, 1" C-Mount TitanTL®, Edmund Optics) has been selected to minimize perspective effects, receiving light parallel to the camera sensor (Figure 15). Firstly, it is essential to ensure that vibrations do not obscure any part of the investigation plane located in the middle of the rod. This problem could arise from perspective effects. Second, it is essential to prevent the surfaces where the laser sheet enters and exits the rod material from being visible, as the reflections/refractions on these surfaces would cause image saturation and saturated the particle images. A telecentric lens addresses these issues by ensuring that light rays are parallel to the optical axis, thus eliminating perspective distortion. Unlike standard lenses, telecentric lenses maintain constant magnification regardless of the object's distance from the lens. This characteristic is crucial in applications requiring precise measurements and imaging, as it prevents any part of the object from appearing larger or smaller due to its position in the field of view.

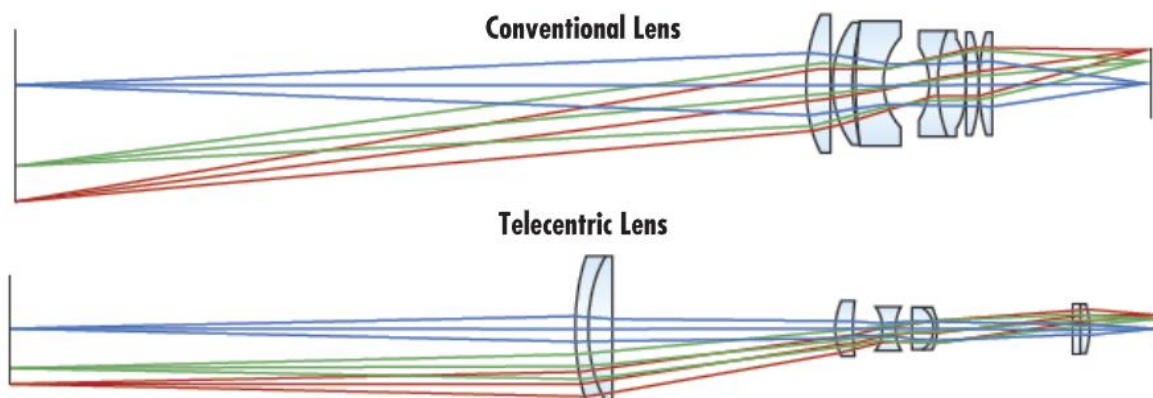


**Figure 16: Comparison of light path between a conventional lens and a telecentric lens.**

The conventional lens shows varying angles of light rays, illustrating its angular field of view (AFOV), whereas the telecentric lens demonstrates parallel light rays, indicating a zero-angle field of view (Edmund Optics, n.d.).



**Figure 17: Telecentric lens for PIV measurement**

Finally, particle selection has been made by considering two main aspects: traceability of the flow and illumination. The condition of neutrally buoyant particles makes the tracers extremely accurate. This condition can be easily satisfied for liquid flows, as in the present case where the working fluid is water, which provides a wide choice of particle materials. Secondly, it is recommended that the diameter of particle images be at least 3 pixels (Raffel et al., 2018). Therefore, ensuring the particle image size matches in the field of view is essential. The objective lens forms an image of the tracer particles in the light sheet on the surface of a CCD image sensor. This lens is characterized by its focal length ( $f$ ), numerical aperture ( $na$ ), and image magnification ( $M_0$ ).  $M_0$  defined as the ratio of the image distance to the object distance. According to Adrian (1991), the diameter ( $d_\tau$ ) of the image of a small tracer particle with a diameter ( $d_p$ ) in the light sheet can be calculated using the following formula:

$$d_\tau = \sqrt{d_{geo}^2 + d_{diff}^2}$$

Here,  $d_{geo} = M_0 d_p$  represents the geometric image diameter, and  $d_{diff} = 2.44 \cdot \lambda \cdot na \cdot (1 + M)$  is the diffraction-limited spot diameter caused by light interference due to the finite aperture of the objective. As a result, hollow glass spheres with 10µm of diameter (Dantec Dynamics) have been chosen as an optimum particle.

A cross-correlation algorithm is then used to calculate the displacement of the particles at each point, achieving a spatial resolution of 0.6 mm. For the present study, the investigation plane (laser sheet plane) corresponds to the symmetry plane of the channel width.

### 2.1.2 High-speed camera (displacement measurements)

Flow visualization and analysis of the displacement of the different cylinders in vibrating mode will be performed using, among others, a high-speed camera: Phantom Miro Digital M310. The Miro 310 camera has 3200 fps at full resolution (1280x800). With a 20-micron (mm) pixel size and 12-bit depth, the camera features high-light sensitivity and great dynamic range. The maximum frame rate at reduced resolution can be increased to 325.000. The camera is piloted by the Dynamic Studio 8 software from Dantecs Dynamics.

## 2.2 Experimental campaigns

|                                            |                                                               |                         |
|--------------------------------------------|---------------------------------------------------------------|-------------------------|
| <b>1<sup>st</sup> measurement campaign</b> | Characterization of the loop                                  | June & July 2024        |
| <b>2<sup>nd</sup> measurement campaign</b> | PIV measurements for the detailed flow field characterization | August / September 2024 |
| <b>3<sup>rd</sup> measurement campaign</b> | FSI measurement                                               | October / November 2024 |
| <b>4<sup>rd</sup> measurement campaign</b> | Force measurement                                             | 2025                    |

A specific meeting with the partners concerned by the results of GOKSTAD will be organized before the second measurement campaign to define the test matrix for the 2<sup>nd</sup> measurement campaign.

The benchmark setup will be defined with the different partners after the 2<sup>nd</sup> measurement campaign.



### 3. Conclusions

The deliverable describes the new water loop designed and built at VKI to characterize FIV in a crossflow configuration. The different components of this new facility, GOKSTAD, are described and illustrated with pictures. The three configurations for which measurements will be taken are also explained: static, FIV, and static with force measurement.

The commission of the facility is ongoing.



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