The DRESDYN project: A new facility for thermohydraulic studies with liquid sodium

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Abstract. For the safe operation of SFR's there is a growing need for large and medium sized liquid metal experiments to study various thermohydraulic and safety aspects, comprising effects such as flow metering, local velocity measurements, gas bubble entrainment, and early gas bubble detection. We give a short description of the new large-scale infrastructure DRESDYN (DREsden Sodium facility for DYNamo and thermo-hydraulic studies) at Helmholtz-Zentrum Dresden-Rossendorf (HZDR). For the planned liquid sodium installations a new experimental hall with an area of approximately 500 m^2 became available in 2017. The total inventory of sodium will be 12 tons. We sketch the liquid-sodium experiments that are planned within the framework of DRESDYN, and delineate some of the technical pecularities, in particular a liquid argon fire extinguishing system. Some development of flow measurement techniques, which are supposed to be tested at various DRESDYN installations, will also be described. They comprise contactless flow-rate sensors, local velocity measurements such as the Ultrasound Doppler Velocimetry (UDV) or the Contactless Inductive Flow Tomography (CIFT), as well as X-ray visualizations of liquid metal two-phase flows.

Key Words: Sodium-cooled fast reactors, Measurement techniques.

1. Introduction

Sodium-cooled Fast Reactors (SFR) have the key advantage of exploiting available fissile and fertile materials much more efficiently than light water reactors. They are also supposed to play a key role in closing the fuel cycle by managing high-level wastes, in particular plutonium and other actinides. Interestingly, SFR's have various intrinsic safety characteristics [1], including a large margin to the boiling point of sodium, a long thermal response time, a primary system that operates near atmospheric pressure, and an intermediate sodium system between the radioactive sodium in the primary system and the power conversion system. With view on the safe operation of SFR's there is a growing need for large and medium sized liquid metal experiments to study various thermohydraulic and safety aspects [2], comprising effects such as flow metering, local velocity measurements, gas bubble entrainment, early bubble detection, and sodium boiling.

The large-scale infrastructure DRESDYN (DREsden Sodium facility for DYNamo and thermo-hydraulic studies) at Helmholtz-Zentrum Dresden-Rossendorf is a platform for large and medium-sized liquid-sodium experiments [3], partly devoted to fundamental problems of geo- and astrophysics [4], partly intended for investigation into energy-related problems, including In-Service-Inspection (ISI) aspects of SFR's and tests of liquid metal batteries [5]. In this paper, we will present the general structure of the DRESDYN project, the main experimental installations, some interesting technical peculiarities such as a liquid argon fire extinguishing system, and some recently developed measurement techniques that are to be tested in the framework of DRESDYN.

2. DRESDYN – Overview

For the liquid sodium experiments to be carried out in the framework of DRESDYN a new laboratory building with approximately 500 m^2 experimental area is now available. Figure 1a shows the building from outside. Its left wing (LW) comprises a workshop, a chemistry lab, and a control room on the first floor. The central hall (CH) gives home to the very sodium experiments. The right wing (RW) contains most of the technical installations, in particular a sodium storage tanks for a total of 12 tons, an electricity supply for up to 2.4 MW, and a liquid argon fire extinguishing system with 15 tons of liquid argon. The cleaning station (CS) in the foreground, equipped with a half-open roof, will serve for cleaning sodium-spoiled installation parts with water.

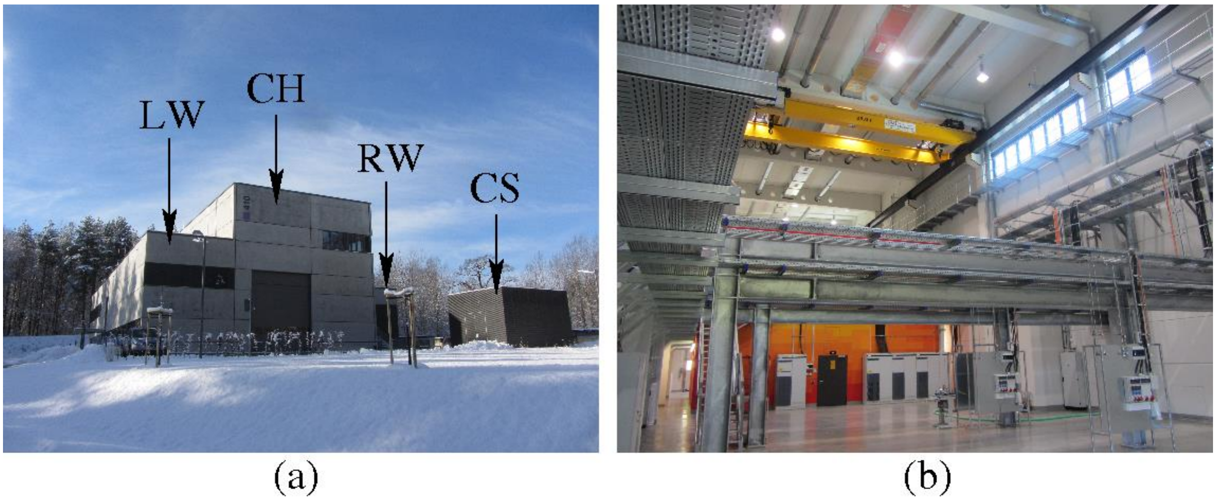

FIG. 1. The DRESDYN building at HZDR. (a) External view, (b) interior of the central hall.

Figure 1b gives an insight into the central experimental hall. The reddish wall in the background is part of a special containment for a large-scale precession dynamo experiment. The two horizontal trusses in the foreground provide the sodium experiments with cooling media, electricity, and control data.

Figure 2 illustrates the general structure and the planned installations, with the separate containment for a precession driven dynamo experiments (P), a large Taylor-Couette experiment (M) for investigations of the magnetorotational instability (MRI) and the Tayler instability, a sodium loop (L) and an In-Service-Inspection experiment (I).

The most ambitious project in the framework of DRESDYN is a large scale precession experiment [3,4] which is intended to work as a homogeneous magnetohydrodynamic dynamo. It consists of a cylindrical vessel of 2 m diameter and height and 3 cm thickness, rotating with up to 10 Hz around its axis, and with up to 1 Hz around a perpendicular axis. The mechanical and safety demands for such a large-scale sodium experiment are tremendous, in particular due to the huge gyroscopic torque (up to 8 MNm) which requires a massive ferro-concrete basement. It rests on 7 columns reaching 22 m into the bedrock. The liquid sodium Taylor-Couette experiment (M) is supposed to continue and combine the recent experiments (using GaInSn) on the helical [6] and the azimuthal [7] MRI and on the Tayler instability [8], and to enhance the available parameter region in order to study the standard MRI, too.

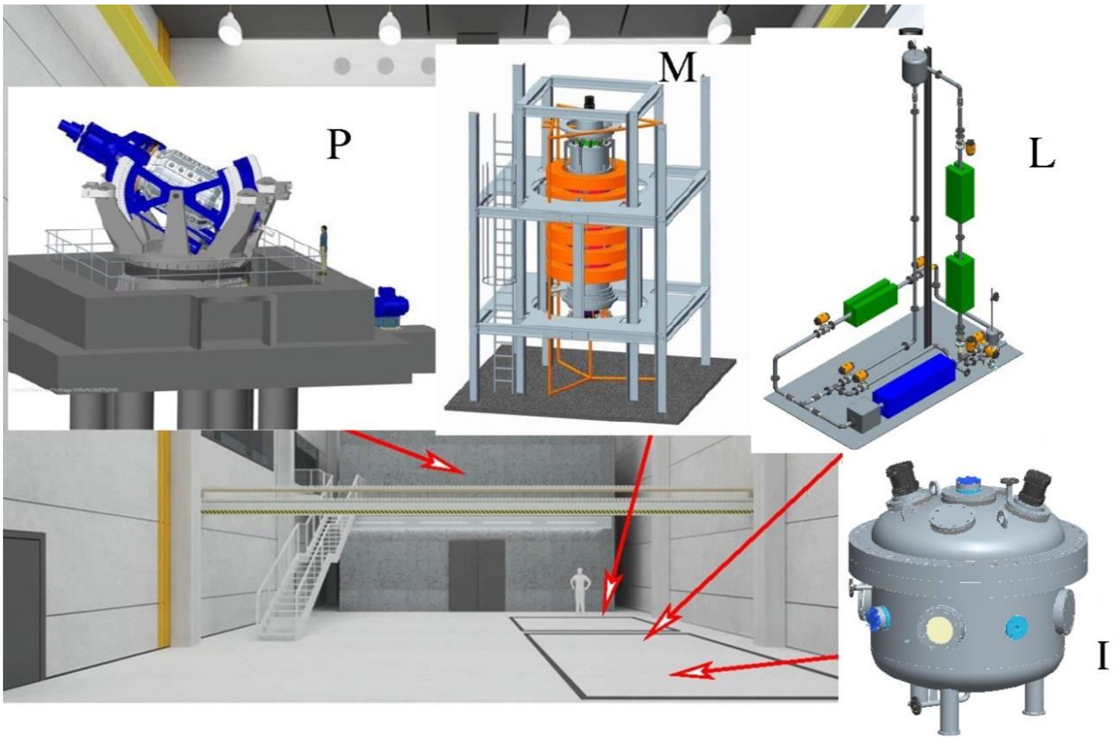

FIG. 2. Interior of the central hall, and the main planned experiments. Precession driven dynamo experiment (P) to be installed in the containment; Tayler-Couette experiment for the investigation of the magnetorotational and the Tayler instability (M); sodium loop (L); ISI experiment (I). A further stand for testing liquid metal batteries, which is not completely specified yet, will complement the list of sodium experiments.

3. Fire extinguishing system

In view of the extreme mechanical parameters of the precession experiment, special care must be taken to prevent, or at least mitigate, any severe hazards in case of sodium leakage. Due to the simultaneous rotation of the vessel around two axes, it would not be possible to quickly drain the sodium into the tanks (as it was one of the key safety measures of the Riga dynamo experiment [9]). For that reason, it was decided to install a fire extinguishing system using liquid argon. It comprises a tank with 15 tons of liquid argon and a condenser for keeping it liquid. In case of an accident, approximately four tons of argon will be injected into the containment where they immediately evaporate at the outflow nozzles. Within two minutes the oxygen concentration falls to approximately 4% which is considered sufficient to extinguish even spray fires, all the more as the temperature drops to around -150°C. After accomplishing this main flooding, the oxygen concentration can be kept low enough for 48 hours by using a secondary, maintenance flooding system. Apart from this, the extinguishing system is designed as a multi-zone system which can protect both the containment as well as the sodium storage room in the basement.

Figure 3 gives an impression of the first experimental test of this fire extinguishing system carried out in January 2016. Based on the data obtained during these tests, the amount of argon to be deployed and the protocol of flooding were slightly adapted to suit the ambitious safety demands.

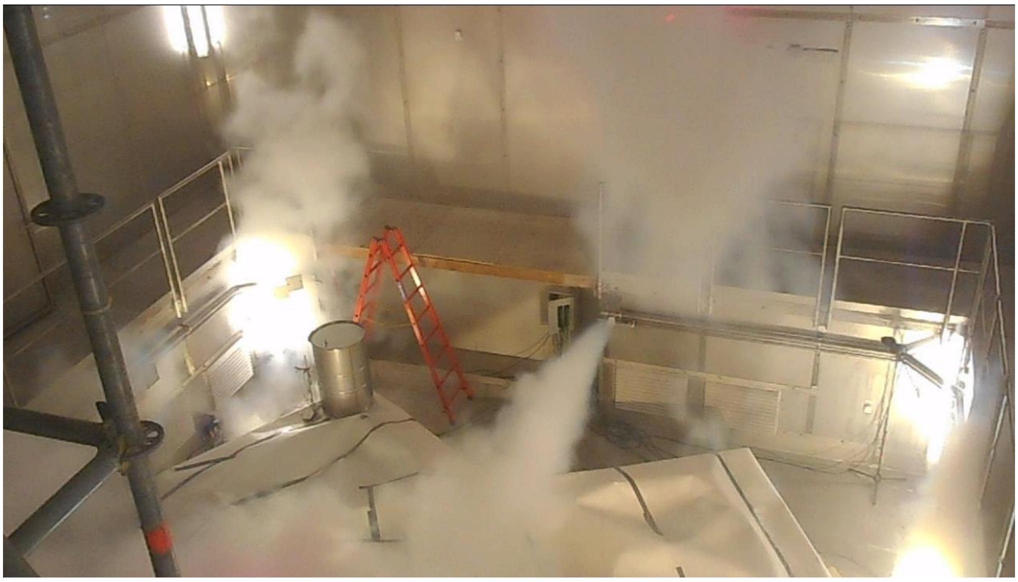

FIG. 3. First test of the fire extinguishing system using liquid argon which evaporates immediately at the outflow nozzles in the containment.

4. SFR related installations for testing measuring techniques

For various purposes, DRESDYN will comprise a standard sodium loop with a horizontal and a vertical test section of 100 mm diameter each (Figure 4). A 30 kW electromagnetic pump will provide a maximum flow rate of 56 m^3/h at 300°C. Both test sections will be equipped with various measurement flanges, and will optionally allow the application of magnetic fields in order to investigate particular MHD flow problems. The vertical test section will be particularly used for investigations of two-phase flows of sodium and argon.

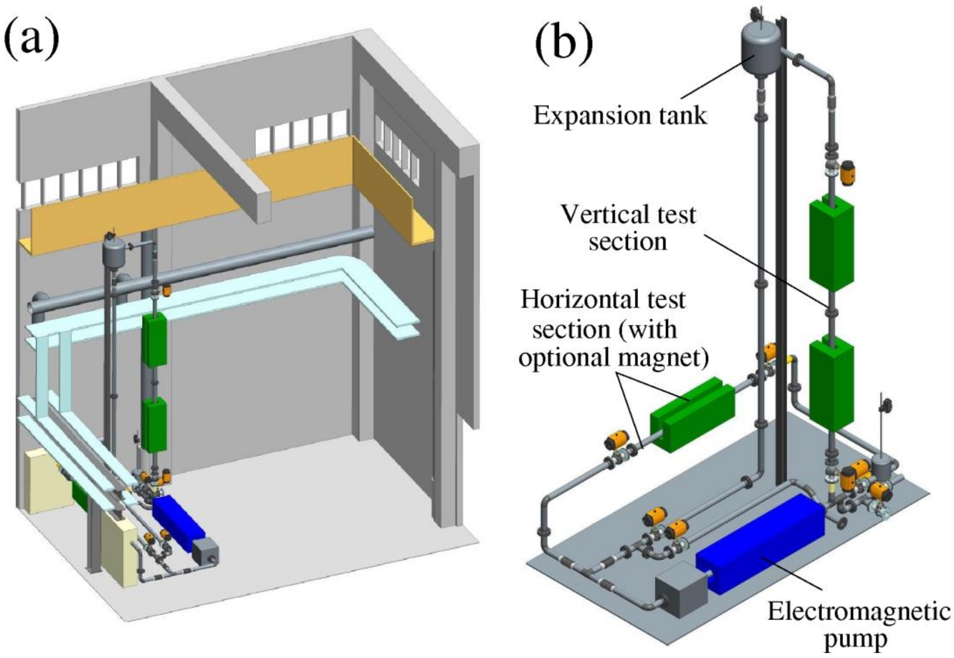

FIG. 4. Planned sodium loop. (a) Situation in the experimental hall, (b) technical details.

Another experimental test stand will be devoted to various In-Service-Inspection experiments and the test of measurement techniques. Figure 5a shows a first variant of this experiment, with a number of flanges for sensors, cables, and feed-throughs of axes for rotational stirring of the liquid sodium. While not completely specified in all detail, Figure 5b illustrates some key ideas of the various measurement techniques to be tested in this stand.

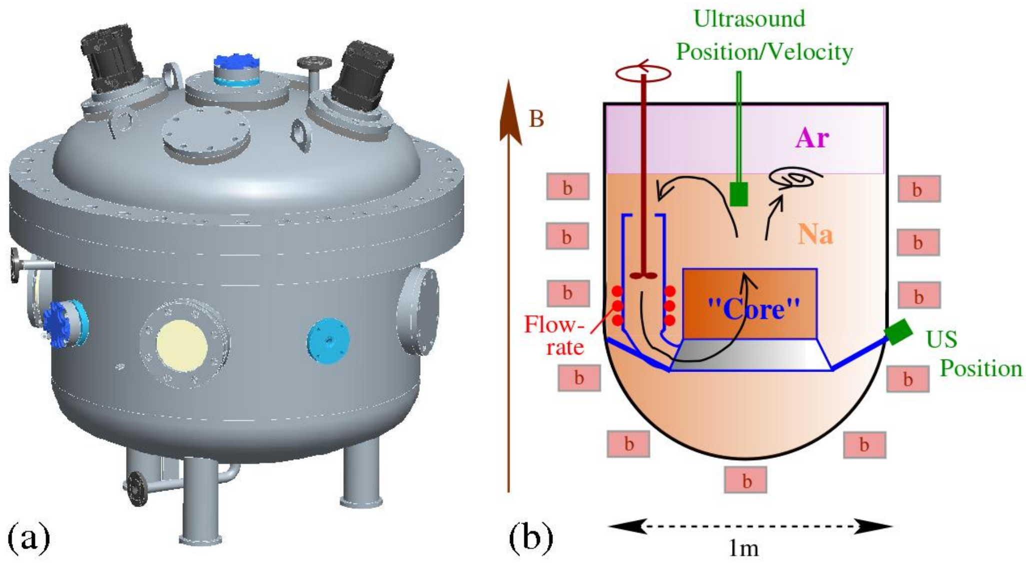

FIG. 5. Planned ISI experiment. (a) Construction of the vessel. (b) Schematic sketch of installations and measurement to be tested at the ISI experiment. One or multiple impellers serve as "primary pumps". The sodium is then guided through a dummy "core", above which its velocity will be measured by ultrasonic and inductive methods. The large-scale magnetic field B serves as the primary field for applying the CIFT-method, which relies on measuring the flow-induced magnetic fields at various positions around the vessel. Various two-phase experiments on gas-entrainment problems are also foreseen.

The importance of testing measurement techniques for liquid sodium results from the need to obtain reliable and accurate global or local flow data at various places of SFR's [10]. The flow rate produced by the primary pumps is an important point in case. Various types of immersed flow rate sensors will be tested at the corresponding position in the ISI experiment. Spatially resolved velocity measurements above the core could help to quickly detect any sort of blockage in the subassemblies. An ambitious, though not unrealistic, project is related to the contactless inductive determination of the complete velocity field structure within the reactor vessel.

One of the measurement techniques to be tested at the ISI experiment is the Ultrasonic Doppler Velocimetry (UDV) which has become a powerful technique [11, 12]. It is able to deliver local velocity profiles along the ultrasonic beam, penetrating into the liquid metal over distances of up to 1 m. The UDV technique can measure velocities ranging from one mm/s up to several m/s, depending on the transducer frequencies which typically are in the range of 1-8 MHz. UDV measurements can be performed by a direct contact between the ultrasonic transducer and the liquid metal, but are also possible through some pipe wall just by contacting the transducer to the outer wall surface. The latter case, however, requires a careful adaption of the acoustic impedances between the melt and the wall. UDV measurements have successfully been performed both in sodium [12] and lead-bismuth flows [13]. The operation of available ultrasonic transducers is limited in temperature up to about 200°C. For higher temperatures, ultrasonic wave-guides have been developed [14]. Successful applications up to about 800°C were reported. Ultrasonic techniques have also been utilized for the characterization of two-phase flows, and for inferring the position of installation parts. The ISI experiment will serve as a test stand for those techniques, too.

A special focus of our activity has been lying on inductive measurement methods. One of them, which is suitable for local velocity measurements, is a version of the well-known Vives probe, also known as potential probe. For measurements of the high velocities in the sodium flow of the Riga dynamo experiment it has been designed in a very robust form with the electrodes positioned at the rim of the cylinder instead of at the tip (Figure 6). Such potential probes are inserted into the liquid metal flow and provide the local velocity component perpendicular to both the applied magnetic field and the connecting line between the two electrode tips.

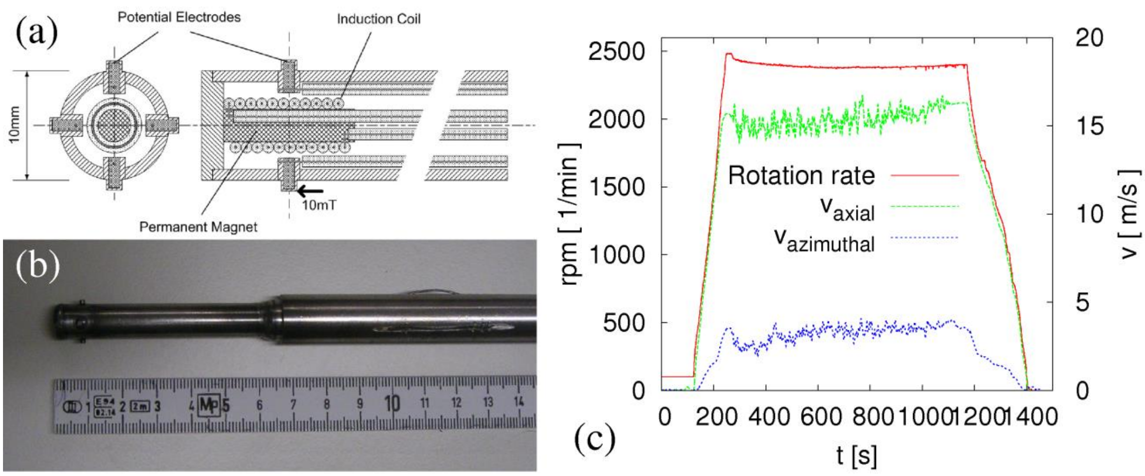

FIG. 6. The robust Vives-type potential probe as developed at HZDR and used for measuring large sodium velocities (up to 20 m/s) in the Riga dynamo experiment. (a) drawing, (b) photograph, (c) propeller rotation rate and axial and azimuthal velocities measured in the Riga dynamo experiment.

Further inductive techniques developed at HZDR are the phase-shift sensor [15] and the transient eddy-current flow metering (TECFM) [16]. The latter one is particularly interesting as it does not need any calibration. Further to this, the absence of any magnetic materials makes TECFM suitable for high-temperature applications as they are relevant for SFR's.

In addition to these local methods, we have also developed a global inductive method that aims at reconstructing entire velocity fields [17]. This Contactless Inductive Flow Tomography (CIFT) relies on the fact that externally applied magnetic fields are disturbed by the flow of a conducting medium. These small flow-induced modifications of the magnetic field are measured outside the liquid metal volume using an array of magnetic field sensors. By using this method, it is possible to reconstruct whole two-dimensional [18] or three-dimensional [19] velocity fields. The time-resolution of this inverse method is in the range of seconds, thus CIFT allows a transient monitoring of complex three-dimensional mean velocity fields. The spatial resolution depends on the number and spacing of external magnetic field sensors. At the ISI-experiment we will also carry out CIFT experiments for inferring the 3D-velocity structure in the vessel (see Fig. 5b).

Another inductive method to investigate two phase flows relies on the dependence of the mutual inductance between neighboring coils on the material properties in their vicinity. The method has been successfully applied for bubble detection in a liquid metal pipe flow [20] and for the determination of the two-phase flow structure in the submerged entry nozzle of a physical model of continuous steel casting [21]. Generic experimental studies on the fluid-induced gas bubble entrainment into liquid metals, using ultrasonic and X-ray diagnostic tools, have been reported recently [22]. These measurements have revealed distinct differences between water and liquid metals, in particular with respect to the process of bubble formation and the coalescence and breakup of bubbles. Corresponding measurements will also be carried out in the ISI-experiment. The set-up of an X-ray lab, dedicated in particular for the investigation of two-phase flows, is planned for the future.

5. Conclusions

In this paper, we have presented the DRESDYN project as a platform for medium and large-scale liquid sodium experiments, partly with geo- and astrophysical, partly with SFR-related background. The building and the sodium infrastructure will be available by the end of 2017, so that first sodium experiments are expected to start in 2018. Apart from the specific experiments discussed in this paper, DRESDYN is open for proposals of further liquid sodium investigations.

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