A new bench for tomographic γ-scanning of fuel rods

H.K. Jenssen[1], B.C.Oberländer
Institutt for energiteknikk, IFE, Nuclear Materials Techology Department, Halden Reactor Project
P.O.Box 40, N-2027 Kjeller, Norway

Abstract

A new gamma-scanning bench has been built at the Kjeller hot-laboratory. The bench is capable of scanning fuel rods in 3-axis (x, y, z) and rotation (θ), which open up new possibilities to perform tomography gamma-scanning. A system for scanning transversal fuel samples is also implemented in the bench. It is possible to scan the whole surface of transversal fuel samples by meandering traces. The result of this scanning is normally correlated to fuel macrographs.

The electronics steering system was produced and the mechanical components of the bench were mounted together on a stable aluminum frame. The electronic department at IFE produced the software we utilize with the gamma-scanning bench.

The new gamma-scanning bench will be installed in the hot cell during the summer. This paper will present the mechanical and electronic details of the bench. The intention of this paper is not to show results performed on actual irradiated fuel rods and ceramography samples. However, the different programmable modes of the bench are explained in the present paper.

***Keywords:** γ-spectroscopy, electro mechanics, linear guides, high purity germanium (HP Ge) detector, digital spectrometer*

1. Introduction

The old gamma-scanning bench from the early seventy was capable of doing longitudinal scanning of irradiated fuel rods and transversal ceramography samples. The system consists of one electrical stepping motor for horizontal movement along the samples. The vertical positioning of the sample was performed manually. The basic idea behind construction of the new bench was to improve the gamma scanning capability of irradiated ceramography samples from one axial system into a two axial system. This idea was further developed into a bench with the possibility to perform gamma-scanning along 3-axis while the fuel rod/ceramography samples also have the possibility to rotate during the measurements. It is now possible to perform tomography gamma scanning of irradiated fuel rods with the improved system. This is a non-destructive PIE method for acquisition of transversal gamma-activity of fuel rod cross-sections. The gamma-scanning of ceramography samples in several orientations was quite time consuming with the old gamma scanning system. The new system is capable of scanning the whole cross-section of the sample during one measurement sequence. The results are normally correlated to information acquired from fuel macrograph, e.g. fuel in-homogeneity and cracks.

The electromechanical details of the new gamma-scanning bench are explained. The bench is equipped with a new high purity gamma-detector and a digital spectrometer from Ortec with many interesting features. Also, the accuracy of the x and y movements were examined and discussed.

2. Bench mechanical layout, electronics & programming modes

The general layout of the gamma-scanning bench is designed with a 3-dimensional mechanical workshop data program from Solid Works. An advantage of this programme is that the bench movements and functionality can be simulated and tested out before any modifications are performed. The general layout of the gamma-scanning

[1] Tel: 0047 63806089 Fax: 0047 63811223 Haakon.Jenssen@ife.no

bench is given in figure 1, and a photograph of the bench is given in figure 2. The bench consists of several linear guides used for the movements in x, y and z directions. The interior of the linear guides is mainly a rotating screw-rod driven by electrical stepping motors. The linear guides consists of high quality components manufactured by Hoerbiger-Origa AB. A sturdy aluminium frame mounted onto the concrete cell wall supports the linear guides and the "handling" table. The "handling" table is made of steel plates and it ensures easy handling of the irradiated fuel rods, sample holders and other devices utilised in gamma-scanning measurements and setups. The steel table and the horizontal linear guide move simultaneously up and down by support of the two vertical guides. The horizontal linear guide supports an aluminium rail manufactured by Melles Griot. The rail is used for installation of the rotating chuck, fuel rod holders and ceramography holders. The linear guides utilised for the z-movement of the sample is located under the "handling" table. The table has a slit above the linear guide that makes possible the movement of the irradiated sample in the z-direction. However, the "handling" table doesn't move under the displacement along the z-direction. This movement along the z-axis is mainly utilised under installation of fuel rods and ceramography samples into suitable holders mounted on the aluminium rail or the horizontal linear guide of gamma-scanning bench. Irradiated fuel rods are mounted into the rotating chuck that is driven by a programmable stepping motor. The rotation of fuel rods is utilised under gamma-scanning measurements, i.e. the rotational scanning mode acquires data at different angular orientations of the sample. This mode is possible to use both for fuel rods and transversal ceramography samples. However, the rotational mode is mainly utilised for initial sample positioning before the gamma-scanning measurements are executed. Tomography gamma-scanning also demands rotation of the fuel rod performed at high angular resolution. The ceramography holder connected to the rotating chuck, the fuel rod holders, the stepping motors and encoders are shown in figure 3.

The stepping motors and encoders are mounted on the different linear guides. The encoders were installed because they serve as absolute position sensors, i.e. the movement of the system is always related to the same origin or coordinate system. The encoders should work for a long time if they are shielded for γ and neutron radiation. The neutron radiation is normally not a problem. However, in some situations as for MOX and very high burnup fuel, the fuel rod emits neutrons and the encoders need to be shielded with neutron absorbers. Shielding the encoders for γ-radiation is performed with lead of suitable thickness surrounding the devices. The stepping motors need drivers and indexers for performing the programmable tasks. The indexers send instructions to the motor drives that generate the necessary signals for the stepping motors to work properly. All communication with the stepping motors is performed with several computer data programmes interacting through the indexers. The system consists of one indexer for each of the basic movements, i.e. one indexer for the x, y and z-movement respectively and one for the rotation of the chuck. The system has one motor drive for each of the linear guides, i.e. altogether five such devices. This means that one indexer is utilised for the two motor drives installed on the vertical guides utilised for the y-movement. The motor drives and motor indexers are shown in figure 4.

The electronics department at the Institute for Energy Technology (IFE) performed the programming of the system. There are several modes of operation incorporated in the system, e.g. the motor modes and several measurement modes. The motor modes consist of graphical user-interfaces where the operator can perform the necessary actions for moving the table, e.g. positioning of the fuel sample relative to the collimator and gamma-detector and for mounting of fuel sample into the holders. The movements of the fuel sample are performed separately for rotation and for each of the x, y and z-axis. The different encoder values are continuously displayed in window of the user-interface so that the operators always should know these parameters. An appropriate ruler or mm scalar appears on the user-interface and the operator will thereby be able to perform movement actions only by performing mouse click and drag operations. The graphical user-interfaces utilised for the x motor mode or movements along the fuel sample are shown in figure 5.

Additionally six measurement modes were programmed and implemented into the steering system of the gamma-scanner. The simplest mode is utilised for linear gamma-scanning, e.g. acquisition of the average γ-activity along the fuel column of the fuel rod or across the ceramography sample. This is exactly what the old system could perform. The operator only needs to punch into the user-interface the acquisition or lifetime for each spectrum measurement, the initial x and y positions, the final x and y position and the move increments. The gamma-scanner can also measures the fuel sample over a rectangular area only by setting different initial and final y-values.

The rotational mode turns the fuel rod or ceramography sample during the measurement, i.e. azimuthally acquisition from 0 up to 360 degrees. This mode is combined with the x and y movements in the tomography measurements.

One other specific measurement is performed by the circular mode. This measurement is utilised under scanning of transversal ceramography samples cut from an irradiated fuel rod. The meandering movements are restricted to the sample surface and this feature minimises the acquisition time compared to the rectangular mode. The result of this measurement is a two-dimensional γ-activity map represented in an image file consisting of regular acquisition points. The meandering motion of the fuel sample must be programmed in accordance with a regular grid pattern that coincides with the sampling positions. The various acquisition modes operate under similar user-interfaces and an illustration is given in figure 6.

3. Bench qualification & testing-out

The accuracy for the basic movements of the bench is assessed by testing-out against a precise calliper connected to the sample holders/linear guides of the bench. The accuracy for the linear guides is always better than 100μm for displacement performed within the total span of the bench. Callipers from Mitutoyo were utilised for testing-out the bench accuracy for movements in x and y directions. The accuracy of the calliper is always better than 10μm within a displacement of 1000mm. The setup utilised in the measurement is given in figure 7. The displacement error is simply the encoder values minus the readings of the calliper and the results from the test are given in figure 8. We observe that the accuracy is approximately 250μm for a total displacement of 700mm in the x-direction. However, the accuracy for the y-direction is within 50μm for a similar displacement. Both values are obviously well within acceptable limits. The better accuracy of the y-movement is probably due to the weight of the bench system that tightens up the rotating screws of the vertical linear guides.

4. Conclusion

The bench with all the specific features is qualified and approved for reliable γ-scanning of irradiated fuel rods and ceramography samples. For instance, the burnup of actual fuel sample could be estimated with the knowledge of the Cs-134, Cs-137 γ-activity distributions and some irradiation specific parameters acquired from code calculations or simulations (e.g. HELIOS).

The measurement bench works quite well together with a high purity germanium detector and a digital spectrometer manufactured by Ortec. The possibility to select more than 16000 energy channels during the acquisition is one of the many interesting features of the digital gamma-ray spectrometer JSPEC jr. 2.0™. Another feature is the new low-frequency rejector (LFR) filter. The low-frequency rejector technology surpasses all signal processing methods for reducing the effect of microphonic and other sources of periodic noise for HPGe and NaI(Tl) spectrometry. This advance in engineering senses the presence of noise that degrades spectral resolution and minimises the effect by digital filtering.

The bench will also be utilised in visual inspection were the fuel rod rotates and moves at specific displacement during image acquisitions. Images of the fuel rods will not be acquired through the hot cell periscope as we normally do. The imaging will be performed through a connecting plug in the hot cell wall instead. This method minimises the use of optical lens systems. However, the imaging must be performed through a light-reflecting mirror that separates the γ-radiation and image information of the fuel rod.

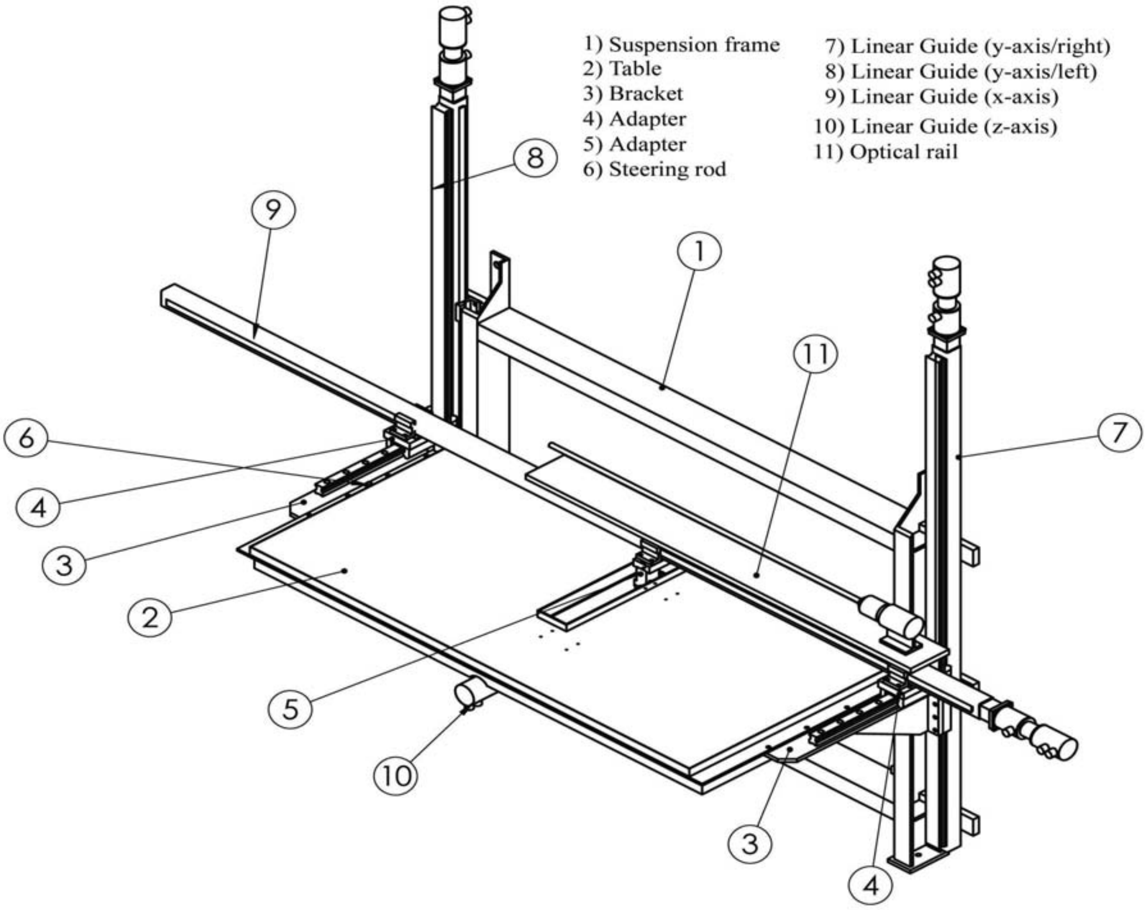

Fig. 1. Prospective view of the gamma-scanning bench. Support frame, linear guides and the fuel rod.

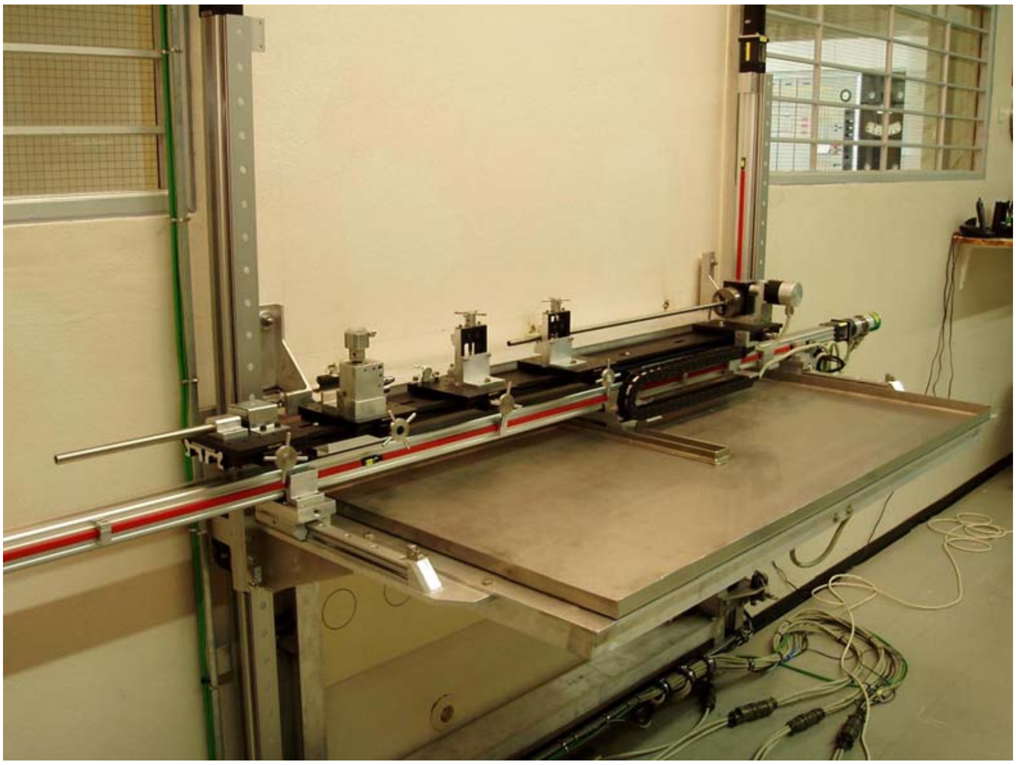

Fig. 2. Photograph of the measurement bench. “Handling” table, linear guides and sample holders.

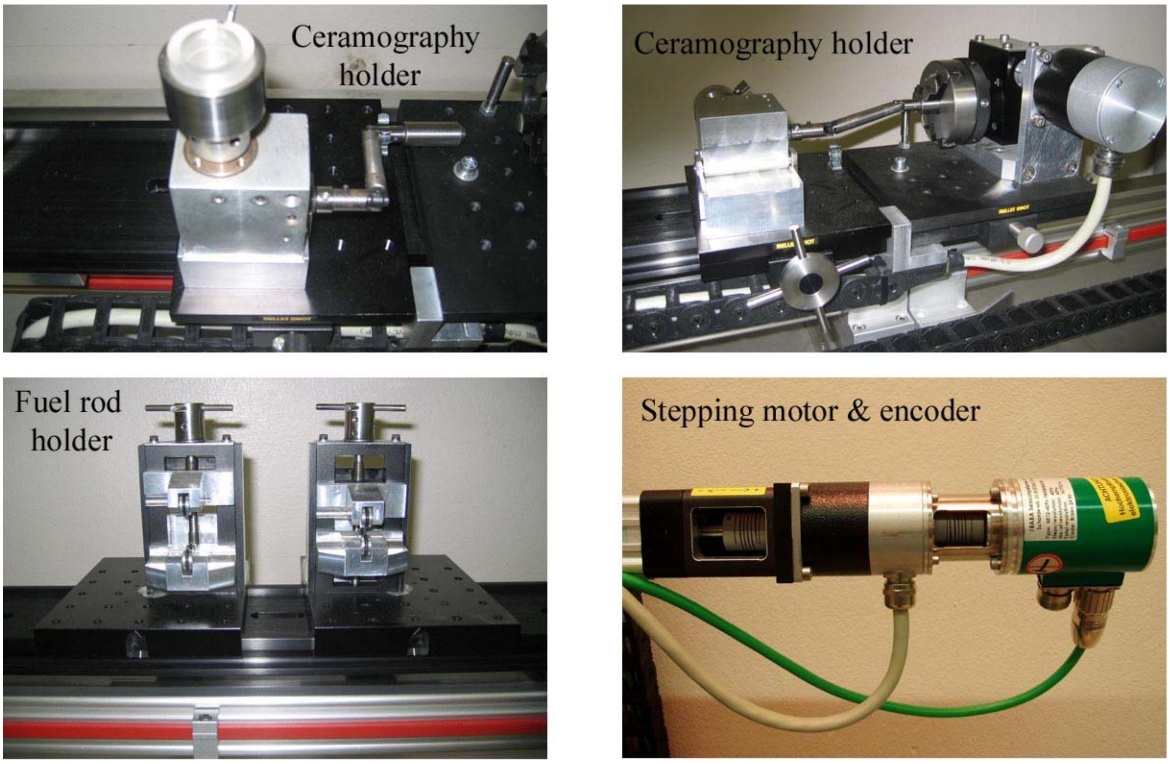

Fig. 3. Ceramography holder, rotating chuck, fuel rod holder, stepping motor & encoder.

Fig. 4. Motor drivers installed in a rack outside the concrete cell.

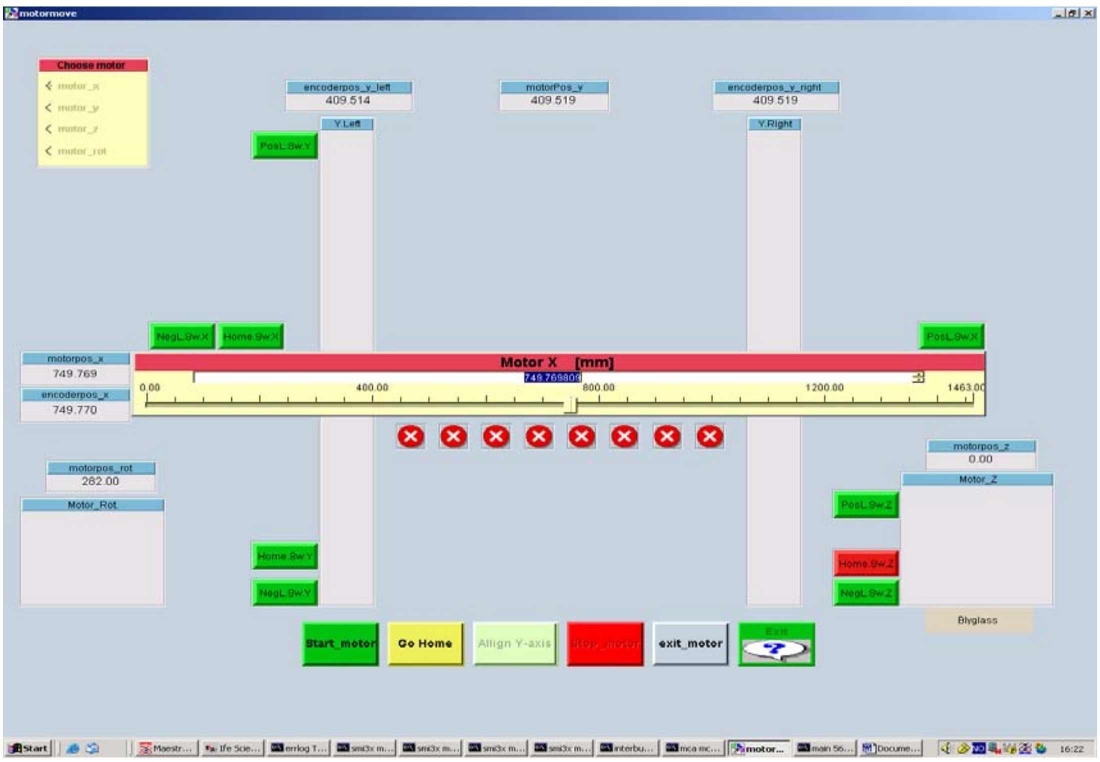

Fig. 5. Motor mode utilised for the x-movement of the irradiated fuel sample.

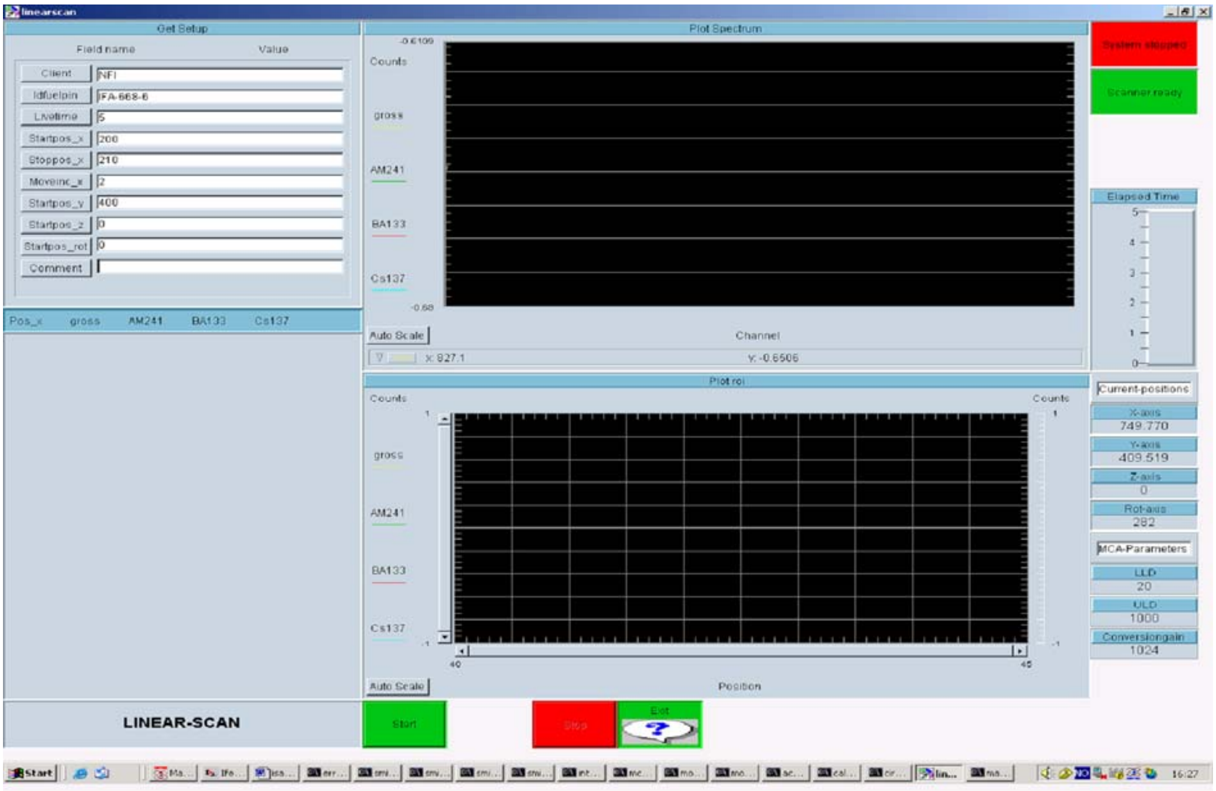

Fig. 6. Linear acquisition mode utilised for displacement along of the irradiated fuel sample.

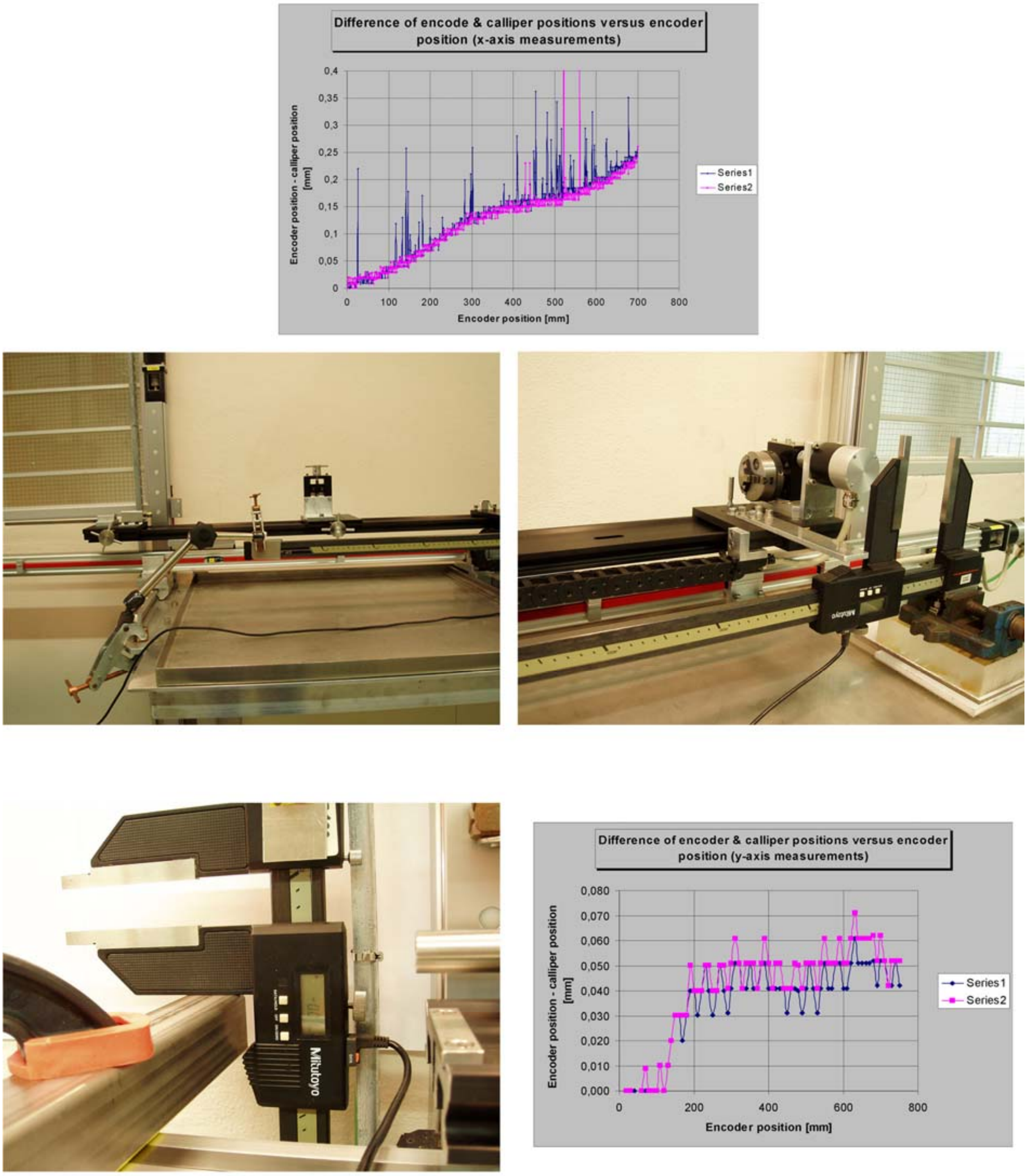

Fig. 7. Test results and calliper setup for the accuracy assessment of the x and y-direction.