X-RAY DIAGNOSTICS FOR USE IN MICROGRAVITY EXPERIMENTS

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ABSTRACT

The development of compact micro-focus x-ray tubes and high-resolution digital x-ray sensors has made the utilization of real-time x-ray diagnostics in the laboratory and on board microgravity rockets possible.

Swedish Space Corporation currently develops a series of systems for in-situ X-ray radiography diagnostics for metallurgy experiments in order to study solidification phenomena and metal foaming in microgravity. These systems are adapted for sounding rocket flight experiments, experiments have also been performed in parabolic flight with good results.

This paper will report on these projects, the technology used and the experience gained so far.

1. X-RAY AS A DIAGNOSTIC TOOL

1.1. Radiation sources

X-ray has been used as a diagnostic tool in medicine and many other areas for over one hundred years. The principle for generation of a radiation beam has largely been the same during this time, using either a naturally radiation emitting material or an x-ray tube. For scientific usage synchrotrons offer a very luminescent radiation source and are widely used.

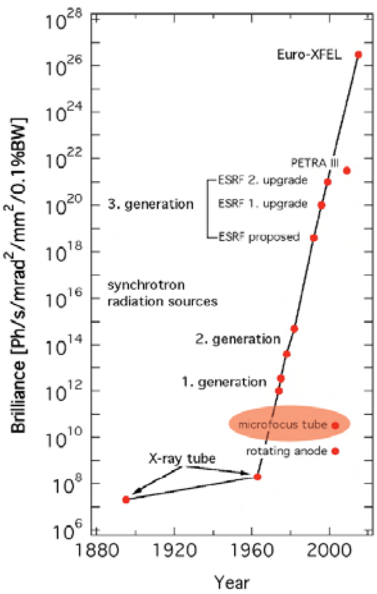

Figure 1. Radiation sources and brilliance

1.2. The digital x-ray diagnostic system

The combination of a microfocus x-ray tube and a digital x-ray detector offers a possibility to follow processes inside materials with x-ray diagnostics. Images can be captured, displayed and stored in real-time.

The conical characteristic of the radiation emitted from the x-ray tube permits a magnification of the examined sample on the receptor by placing it closer to the x-ray source.

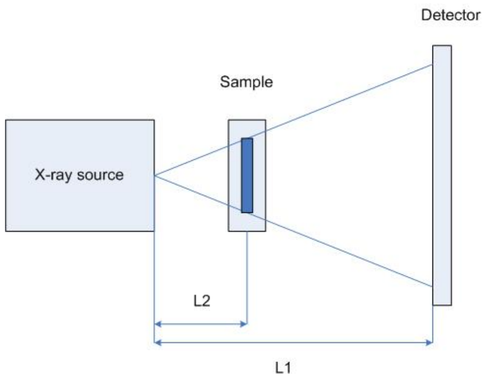

Figure 2. geometrical magnification of object on detector

2. THE X-RAY SOURCE

The advantage of the x-ray tube for generation of radiation for experimental usage is clear; It offers possibilities to regulate the energy spectrum by selecting the anode material of the tube and the accelerating voltage. The intensity of the radiation can be controlled. It is relatively easy to accommodate in a lab. It is also safer from the operator's point of view since no radiation is at hand when the unit is turned off.

In recent years micro-focus x-ray sources with smaller focus-points have been developed and are commercially available. These sources deliver a more homogenous radiation which means that a higher resolution in the images can be achieved and smaller structures can be visualized. At the same time this limits the effect possible to get out of the x-ray tube.

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The focus spot of an advanced x-ray tube can be in the order of 10 µm to below 1 µm, to be compared with standard x-ray tubes which has spot-sizes around 1 mm.

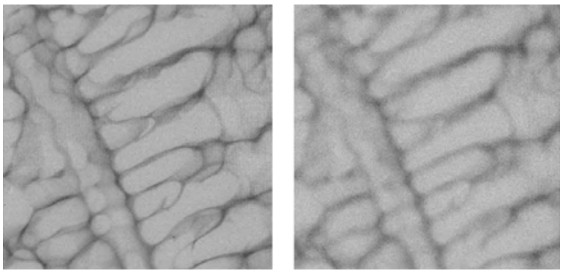

Figure 3. Focus spot size effect on image quality: left 3µm, right 7 µm

The selection of anode material decides the characteristics of the emitted radiation. This must be chosen to match the diagnostics required in the experiment.

3. THE X-RAY DETECTOR

High resolution digital X-ray detectors have come to market recently. Two major types exist: Dedicated X-ray sensors and digital cameras converted for x-ray usage.

3.1. Scintillator

Common for both types of x-ray detectors are that the sensor operates mainly in the visual light spectrum and the radiation therefore is converted to visible light by a scintillating material placed close to the detector.

Several types of scintillating materials are used, one commonly used material is CsI. This material can be used as is, but its chemical properties also allow to grow it in a needle like structure on a supporting plate. This reduces the spreading of light in the material and thus enhances the image quality on the detector.

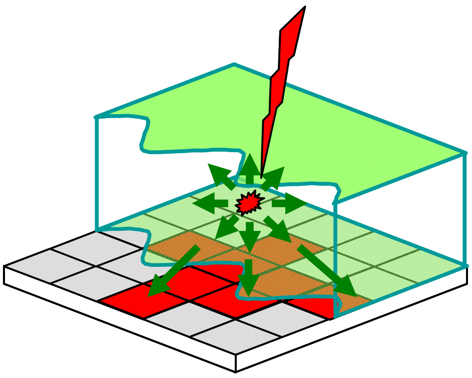

Figure 4. Scintillator priciple

A new development is the Structured Scintillator that utilizes channels etched in a silicone wafer. These channels are covered with a light reflecting material and then filled with a scintillating material. Each channel will then work as a light guide for the converted radiation, minimizing the light spread “blooming” and improving the image quality.
This technique is developed and patented by Scint-X AB, Sweden. A more thorough explanation of the technique is contained in the paper by Ms. A. Sahlholm in this conference.

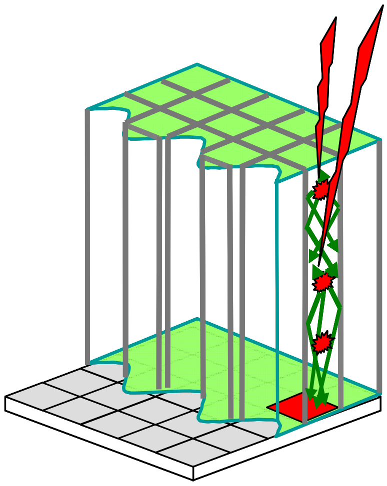

Figure 5. Structured scintillator principle

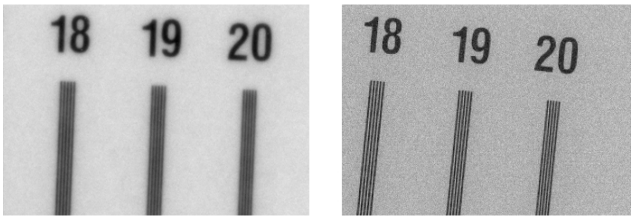

Figure 6. Comparison of image from needle type scintillator and structured scintillator

3.2. Dedicated x-ray sensors

These sensors feature a large active sensing area, up to 120x120 mm. The image elements are typically > 50 µm.

3.3. X-ray cameras

Digital cameras converted for usage in the X-ray spectrum have smaller sensor area and thus smaller pixel size. Chip sizes can be around 24x36 mm or even larger with a pixel size of around 10 µm.

4. SAFETY

To be able to operate an X-ray source as a diagnostic tool adequate safety measures must be taken. The rules for radiation protection are not yet fully harmonized within the EU and the method of ensuring compliance may vary between countries.

The main safety precautions used are:

- Shielding
- Safety devices to ensure that no radiation is emitted when enclosure is opened
- Warning signs
- Operator training
- Established procedures for operation and for emergency cases

5. XRMON-FOAM MODULE ON MASER 11

The XRMON-foam module flown on MASER 11 contained one metal foam furnace and an X-ray diagnostic system. This was the first microgravity experiment ever using X-ray diagnostics in Europe, possibly in the world.

5.1. The experiment

The experiment sample was enclosed in a crucible made of boron nitride, a material that is highly x-ray transparent and can manage high temperatures under ambient conditions. A challenge was to provide good temperature homogeneity at the same time as no heaters could be placed in the x-ray path.

The crucible was enclosed in insulation, efficient enough to keep surface temperature low enough for handling.

During the 46:th ESA parabolic flight campaign the efficiency of this concept was verified, and around 20 experiments observed in microgravity with an image capture speed of 1 frame/s.

The experiment was flown on MASER 11 in May 2008. One sample was processed with good results during the flight and image storage with 1 f/s stored on-board during the whole flight. The results of this experiment are presented in the paper of Dr. Francisco Garcia Moreno in this conference.

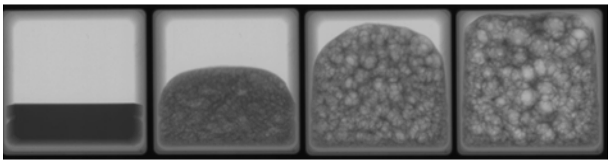

Figure 7. Foam generation during XRMON-foam flight

5.2. The diagnostic system

The requirement on the resolution was 20 µm and the sample size was 20x20x10 mm. By applying a geometrical magnification factor of 3 a dedicated x-ray sensor with an active area of 120x120 mm could be used. This gave ample space to accommodate the furnace in the x-ray path.

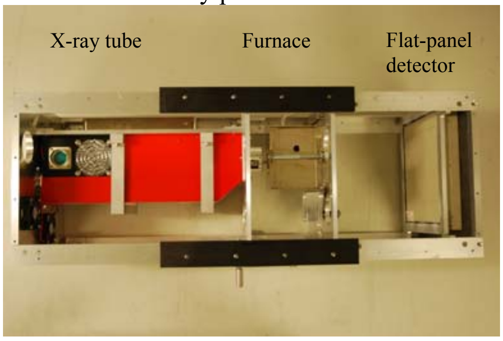

Figure 8. XRMON-foam experiment x-ray chamber (opened)

A "classic type" X-ray tube was used; the anode material was Tungsten with a focus spot of < 7 µm at the working energy (80kV, 100µA).

5.3. Safety precautions

A modular safety system was implemented and used both for the parabolic flight and for the sounding rocket module. This system comprised:

- A shielded box enclosing the radiation area of the experiment system. - Safety switches that disabled radiation when the access hatch was opened, and
- Red warning light flashing when radiation was active

All personnel operating the module were trained according to the regulations of the Swedish Radiation Protection Authority (SSM).

6. XRMON-DIFFUSION MODULE ON MAXUS 8

The XRMON-diffusion module is to be flown on MAXUS 8 and contains three identical diffusion couple furnaces and one X-ray diagnostic system.

6.1. The experiment

The experiment samples are enclosed in crucibles made of carbon, each enclosed in an experiment chamber of quarts glass, to withstand the high experiment temperatures the experiment chamber is evacuated. The molybdenum heater wire is arranged to not interfere with the image of the sample. To preserve the sample a cooling gas stream will be applied at the end of the microgravity time.

6.2. The diagnostic system

The requirement on the resolution is 25 µm and the sample size is Φ 1.5 x 30 mm. By applying a geometrical magnification factor of 2 a dedicated x-ray sensor with an active area of 120x120 mm all three furnaces can be hosted in the x-ray path.

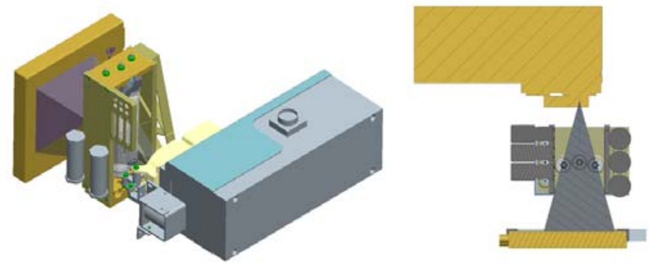

Figure 9. XRMON-diffusion experiment x-ray path: side view / top view

A "classic type" X-ray tube will be used, of the same type as in the XRMON-foam experiment. The anode material will be Tungsten with a focus spot of >7 µm at the working energy (100kV, 100µA).

6.3. Safety precautions

Based on the experience from XRMON-foam a similar safety system and safety approach as used for MASER 11 will be used also for XRMON-diffusion.

7. XRMON-GSTP TECHNOLOGY DEMONSTRATOR

Within the XRMON-GSTP study a high resolution X-ray diagnostics facility is being developed. This facility is hosted by Technisches Universität Dresden and comprises a Transmission Type Microfocus X-ray tube, a Digital X-ray camera and a Structured Scintillator.

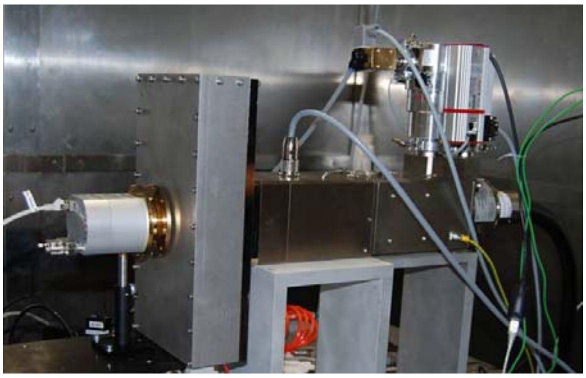

Figure 10. Technology demonstrator.

7.1. Design goals

The goals for the facility is to achieve an effective resolution ≤ 5 µm with a frame-rate ≥ 2-3 Hz and an exposure time of 300 ms.

The anode material for the X-ray tube is selected to be Molybdenum, to maximize the contrast for Aluminum-Copper alloys.

This facility is ready for evaluation tests and will be evaluated by scientists within the XRMON-MAP program in the near future. Preliminary tests have already shown good results.

8. XRMON-GF ON MASER 12

The XRMON-GF (Gradient Furnace) module is suggested to be flown on MASER 12 in 2010 or 2011 and will contain a gradient furnace and an X-ray diagnostic system.

8.1. The experiment

The experiment samples will be melted in a Bridgman furnace with two heating zones and then solidified directionally. The solidification front will be studied during the microgravity time.

8.2. The diagnostic system

The requirement on the effective resolution is 5 µm (2.5 µm pixel) and the sample size is 10 x 50 mm. The complete sample can not be observed as this would need a larger X-ray detector than is available at the time being. The observed area in this resolution will be approximately 2.5x2.5 mm.
By applying a geometrical magnification factor of 10 a digital X-ray camera with an active area of 24x36 mm can be used. The large magnification factor demands that the as much as possible of the radiation delivered by the x-ray tube is used. Thus a transmission type X-ray tube must be used in order to be able to minimize the distance between the focus spot and the sample.
To improve the image quality a structured scintillator will be used together with the digital x-ray camera, as developed in the GSTP-study.

9. CONCLUSION

X-ray diagnostics have shown to be a good diagnostic tool both on ground and in microgravity. By a knowledgeable selection of components a variety of different materials can be observed at different resolutions, exposure times and frame rates. It has been shown that the safety margins for ionising radiation can be adhered also in sounding rocket payloads. The latest technology developments are currently evaluated and show good promise to offer higher resolution and image quality than have ever been possible in the lab, without using synchrotron radiation.