MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

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Cooling water calorimetry measuring results from the first years of ASDEX Upgrade operation

Thomas Richter

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CONTENTS

Abstract

At the tokamak ASDEX Upgrade an extensive cooling water calorimetry system was installed. This system has measured the toroidal and poloidal distributions of the energy deposition by monitoring the temperature rise of the cooling water in 80 separate cooling units in the divertor plates and the central heat shield. The report describes the cooling water calorimetry measuring data from the first years of ASDEX Upgrade operation. The measurements show, that there exist no toroidal asymmetries in the energy deposition on the divertor plates for all kinds of ohmic discharges and for ICRH discharges with a toroidal magnetic field directed opposite to the plasma current. However, Neutral Beam Injection causes a toroidal asymmetric energy deposition profile. Furthermore the reduction of the poloidal in–out asymmetry of the energy load at the divertor plates due to magnetic field reversion was detected. Making up the general energy balance of ASDEX Upgrade, adding the energy detected by the cooling water calorimetry system and the radiation loss energy measured by the bolometry diagnostic, one gets 92 % – 97 % of the energy input.

1. Introduction

One main task in nuclear fusion research is to solve the problem of power exhaust from the magnetoplasmas [1]. In this connection it is important to get information on the toroidal and poloidal energy deposition distribution at the first wall and the divertor target plates for finding out safe operational conditions to prevent accidents due to local material overheating. The energy deposition distribution depends on various factors, for instance on radiation and heat conduction in the scrape off layer and in the divertor, on plasma current and magnetic field direction, on the existence of magnetic islands due to small magnetic coil displacements and on positioning of the additional heating devices.

First detailed experimental studies on energy deposition asymmetries were executed at the ASDEX tokamak using a poloidal and toroidal resolving cooling water calorimetry [2,3]. Based on the ASDEX experience at ASDEX Upgrade the most extensive cooling water calorimetry diagnostic ever installed at a tokamak till now was built up.

The tokamak ASDEX Upgrade consists toroidally of 16 segments. Figure 1 shows the basic structure of such a segment. The plasma facing surfaces of the metallic heat shield, of the divertor plates and of the passive stabilization loop are covered by graphite tiles. Metallic tubes conducting the cooling water flow are installed at the corresponding opposite surfaces. Additional cooling circuits are mounted on the outer skin of the vacuum vessel.

Each single divertor plate segment and each heat shield segment is one individual cooling unit. The passive stabilization loop is divided into two and the vacuum vessel skin into eight cooling units. Furthermore, each Faraday screen of the four ICRH antennas contains an individual cooling unit.

To calculate the energy transported by the cooling water in each single cooling unit of the tokamak, one has to measure the temperature difference ΔT of the cooling water downstream and upstream near the individual cooling units during the cooling phase of the tokamak operation. Furthermore, one needs to know the cooling water flow per time unit.

The sensors for the cooling water calorimetry diagnostic are platinum resistor thermometers and dynamic pressure probe flow meters, located in the cooling water system near the individual cooling units. The noise band width for obtaining toroidal and poloidal asymmetries in the energy deposition profile during a single shot is 30 kJ. That means, as a response to uniform energy deposition on the divertor plates and heat shield segments one gets a scattering of ±15 kJ around the mean value due to electronic bit noise in the data acquisition system. For detailed information on the sensors and on the data acquisition system see [4] and [5].

2.Measuring results from the first years of ASDEX Upgrade operation

The first years of ASDEX Upgrade operation were characterized by a lot of ohmic discharges with relatively low energy input. A main topic of the last years programme was the study of Vertical Displacement Events. So a large number of the ASDEX Upgrade shots ended with disruptions. As well low energy ohmic discharges as disruptive ending discharges are not useful for cooling water calorimetry analysis. At shots with relatively low energy input, for instance 350 kA plasma current, 1 V loop voltage, and 1.5 s Flat–Top, the cooling water calorimetry diagnostic works very close to its lower limit of sensitivity, because the system layout was optimized for plasma pulses with about 10 MW energy input and a Flat–Top duration of about 5 s. During disruptions eddy currents are induced in the cooling water tubes leading to cooling water temperatures which are not correlated with the energy distribution on the target plates during the most time of the plasma pulse. This was concluded from the differences up to a factor of 3 of the calculated energy depositions by thermography, wall thermometry, and cooling water calorimetry for disruptive ending shots. For shots without disruptions there are no differences between these three diagnostics within the range of measuring uncertainties. These facts lead to the conclusion, that shots with disruptions are not useful for cooling water calorimetry analysis of the plasma pulse energy deposition profile. Nevertheless, there exists already a certain amount of useful shots from the cooling water calorimetry point of view. Most of them are ohmic discharges at 600 kA and 800 kA. Some shots were made with considerable additional heating power – as well ICRH as Neutral Injection.

All shots considered below are deuterium discharges in single null configuration (see Fig. 1). The discussion mainly concentrates on the energy deposition profile of the lower outer divertor plate. This target plate is the most energy loaded component of ASDEX Upgrade.

Figure 2 shows the energy deposition profile on the lower outer divertor plate for a 1.2 MA shot with relative high energy input of 2.16 MJ Neutral Beam Injection. One can see a small but significant asymmetry in the toroidal energy deposition profile, the maximum occuring close the injection port. A significant asymmetry in the toroidal energy deposition occurs too in 1 MA Neutral Injection discharges (see Fig. 3). In contrast to this behaviour of discharges with Neutral Beam Injection, pure ohmic discharges have not any toroidally asymmetrical patterns in the toroidal energy deposition profiles. Figures 4–9 show ohmic discharge examples for different main field / plasma current – combinations. Also discharges with ICRH and a toroidal magnetic field directed opposite to the plasma current ($B_t < 0$, ion grad-B drift away from X-point) showed no toroidal energy deposition asymmetries (Fig. 10). The measurements gave first hints of small toroidal asymmetries in deuterium discharges with ICRH, $q_a \approx 5$ and a toroidal magnetic field in the same direction as the plasma current ($B_t > 0$, ion grad-B drift towards X-point), but due to the small number of experimental data for this operational regime finally conclusions on that point couldn't drawn at this stage.

In the Single Null plasma configuration energy deposition occurs primarily on the divertor plates intersected by the separatrix. There is also an asymmetry in the energy deposition on the outer and inner divertor target plate. The factor for the energy load on the outer target plate compared with the inner targets for ohmic discharges with $B_t = -2\,\mathrm{T}$ ranges between 2.2 and 3.5 and, for discharges with $B_t = +2\,\mathrm{T}$, between 1.2 and 1.7. For discharges with Neutral Beam Injection the balancing effect due to main field reversion is about 50 % smaller than in ohmic discharges. What causes different symmetry behaviour is not clear at this stage. Asymmetries could be caused by a particular magnetic asymmetry which could be resonant in one but not in the other pitch direction (that would mean the B_t direction with respect to the plasma current direction is a good parameter for discussing it). Also shadowing effects could depend on B_t–sign. On the other hand there might be a difference in the sensitivity of the configuration depending on diamagnetic heat flow effects. In this case the ion grad-B drift direction with respect to stagnation point would be important.

Considering the energy balance of ASDEX Upgrade, the output energy detected by the cooling water calorimetry system amounts to 60 % – 85 % of the total input energy. Adding the radiation loss energy measured by the bolometry diagnostic, one gets 92 % – 97 % of the energy input.

All energy measurements with the cooling water calorimetry diagnostic are consistent with the measurements of the wall thermometry diagnostic within the accuracy of these experimental systems. In particular, the wall thermometry diagnostic also showed the reduced in–out asymmetry at the divertor plates in the discharges with positive magnetic field. Furthermore, the temperature rise is largest in the tiles corresponding to the positions of the separatrix.

3. Conclusions

The cooling water calorimetry system at the tokamak ASDEX Upgrade has measured the toroidal and poloidal distributions of the energy deposition by monitoring the temperature rise of the cooling water in 80 separate cooling units in the divertor plates and the central heat shield. The measurements show, that there exist no toroidal asymmetries in the energy deposition on the divertor plates for all kinds of ohmic discharges and for ICRH discharges with a toroidal magnetic field directed opposite to the plasma current. More experimental data must be taken for ICRH discharges with a toroidal magnetic field in the same direction as the plasma current to get a final statement on the energy deposition profile in this case. However, Neutral Beam Injection causes a toroidal asymmetric energy deposition profile at the divertor plates. Furthermore the reduction of the poloidal in–out asymmetry of the energy load at the divertor plates due to magnetic field reversion was detected. It was shown, that the cooling water calorimetry diagnostic provides very important data for making up the general energy balance of ASDEX Upgrade.

Unfortunately due to relatively low energy input into ASDEX Upgrade and a programme, mainly determined by the study of Vertical Displacement Events, the conditions for the cooling water calorimetry analysis were not good during the first years of the AS-

DEX Upgrade operation. The situation should change in the future. More interesting experiments are expected for the cooling water calorimetry system, going on to higher input energies and lower q_a–values. The ASDEX–experience and the experience from the first years of ASDEX Upgrade operation show, that the cooling water calorimetry is a useful diagnostic, which should be an integral part also of the currently discussed ASDEX Upgrade divertor II.

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3. Evans, T. E.; The ASDEX Team: IPP–Report III/154, Garching 1991.
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5. Richter, Th.; Vernickel, H.: Review of Scientific Instruments 65(1994)(in print).

FIGURES

Fig. 1: Schematic cross section of the ASDEX Upgrade vacuum vessel. DP – Divertor Plate; HS – Heat Shield; PSL – Passive Stabilization Loop; FS – Faraday Screen. Besides the separatrix for single null configuration is shown.

Fig. 2: Toroidal energy distribution profile at the lower outer divertor plate measured by cooling water calorimetry. Discharge (shot 3702) in deuterium with 1.2 MA plasma current, −2 T main field and 2.16 MJ Neutral Beam Injection. The injector port is located in segment 15.

Fig. 3: Toroidal energy distribution profile at the lower outer divertor plate measured by cooling water calorimetry. Mean value from the shots 4033; 4038; 4075: discharges in deuterium with 1 MA plasma current, −2 T main field and with Neutral Beam Injection.

Fig. 4: Toroidal energy distribution profile at the lower outer divertor plate measured by cooling water calorimetry. Mean value from the shots 2785; 2801; 2804; 2827; 2969; 3258; 3366; 3367; 3585; 3612; 3638; 3669: ohmic discharges in deuterium with 600 kA plasma current and −2 T main field.

Fig. 5: Toroidal energy distribution profile at the lower outer divertor plate measured by

cooling water calorimetry. Mean value from the shots 2792; 2875; 2913; 3083; 3624; 3625: ohmic discharges in deuterium with 800 kA plasma current and +2 T main field.

Fig. 6: Toroidal energy distribution profile at the lower outer divertor plate measured by cooling water calorimetry. Mean value from the shots 2789; 2807; 2810; 2856; 2996; 3368; 3461; 3568; 3586; 4025: ohmic discharges in deuterium with 800 kA plasma current and −1.3 T main field.

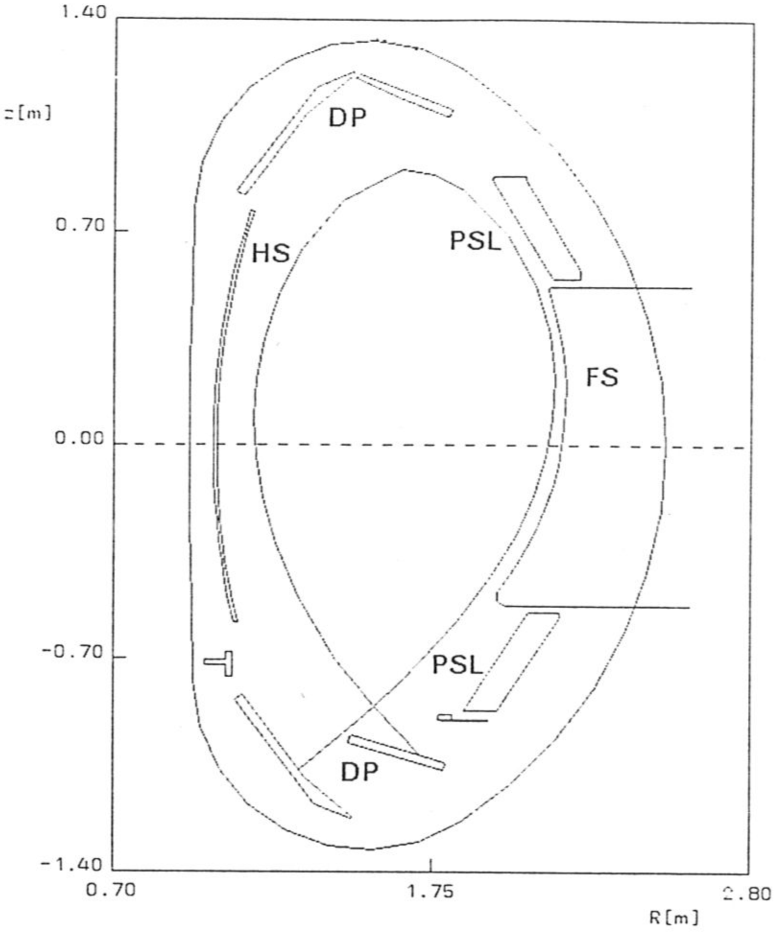
Fig. 7: Toroidal energy distribution profile at the lower outer divertor plate measured by cooling water calorimetry. Mean value from the shots 2793; 2846; 2858; 2860; 2861; 2974; 3064; 3065; 3066; 3068; 3370; 3371; 3373; 3374; 3375; 3376; 3451; 3453; 3454; 3618; 3619; 3620; 3621; 3626; 3627; 3628; 3869; 3870; 3918; 3919; 3921; 3924; 3926; 3927; 3929; 3930; 3960; 3963; 4009; 4010; 4011; 4012; 4026; 4048; 4052; 4055; 4060; 4061; 4062; 4063; 4064; 4065; 4071; 4074: ohmic discharges in deuterium with 800 kA plasma current and −2 T main field.

Fig. 8: Toroidal energy distribution profile at the lower outer divertor plate measured by cooling water calorimetry. Mean value from the shots 3596; 3597; 3598: ohmic discharges in deuterium with 1 MA plasma current and −1.7 T main field.

Fig. 9: Toroidal energy distribution profile at the lower outer divertor plate measured by cooling water calorimetry. Ohmic discharge (shot 3701) in deuterium with 1.2 MA

plasma current and $-2\,\mathrm{T}$ main field.

Fig. 10: Toroidal energy distribution profile at the lower outer divertor plate measured by cooling water calorimetry. Mean value from the shots 2769; 2770; 2771; 2772; 2773; 2774; 2836; 2838; 2839; 2843; 2845; 2847; 2848; 3387; 3388: discharges in deuterium with 800 kA plasma current, $-2\,\mathrm{T}$ main field and with ICRH (ICRH input energy varies from shot to shot).



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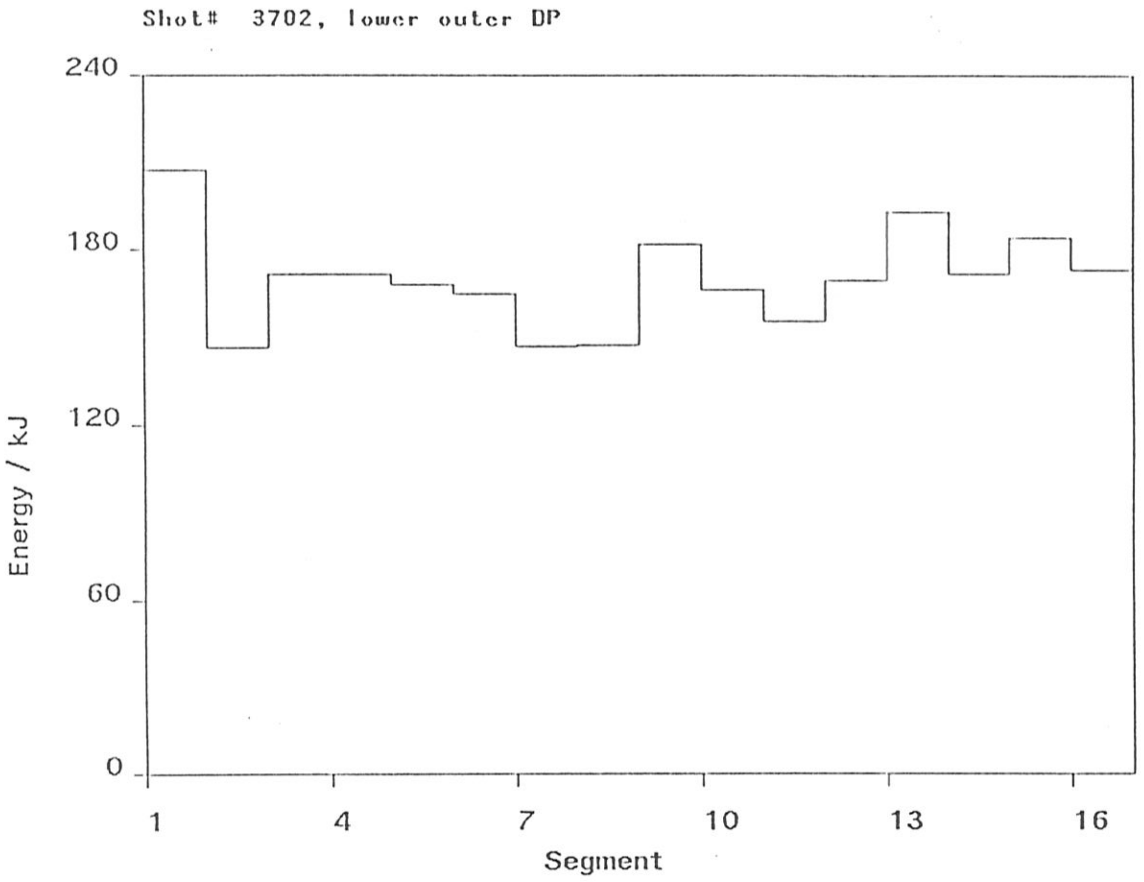
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120
60
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Energy / kJ
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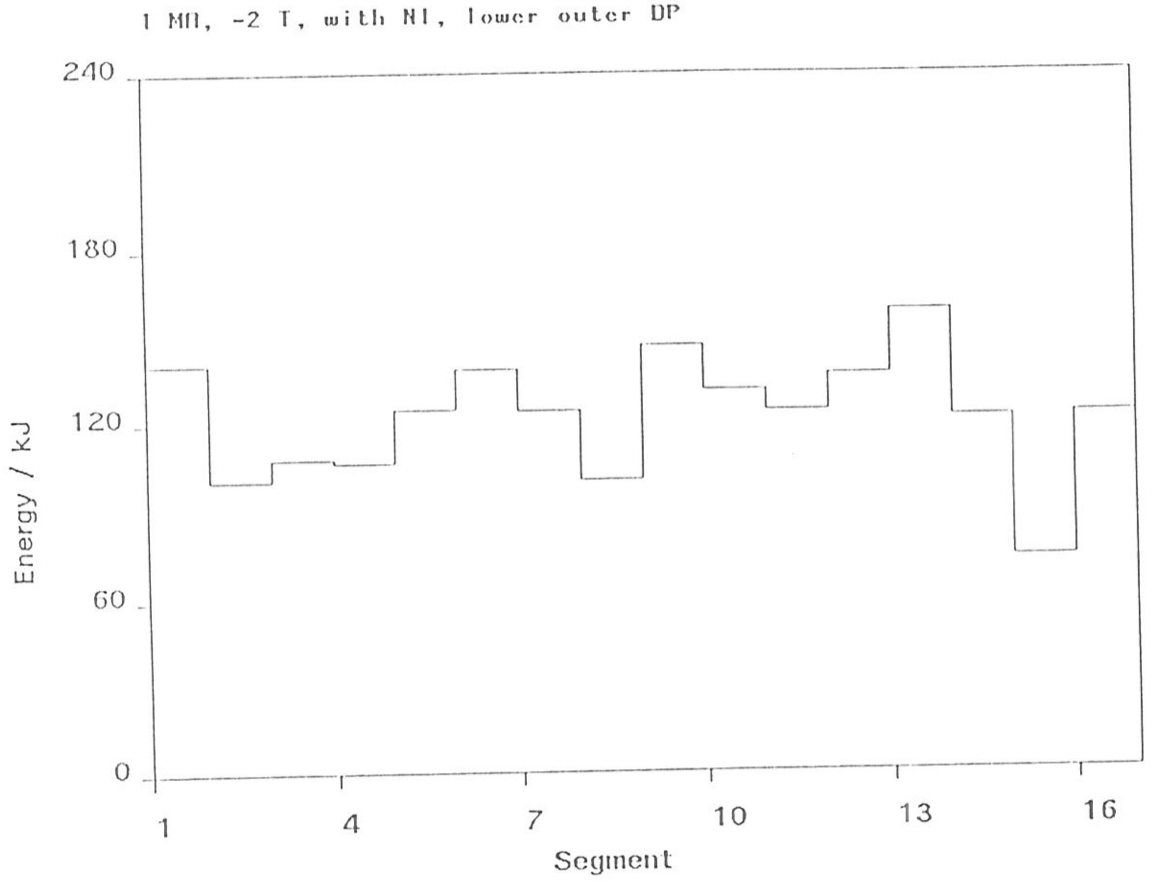
4
7
10
13
16
Segment

Figure 2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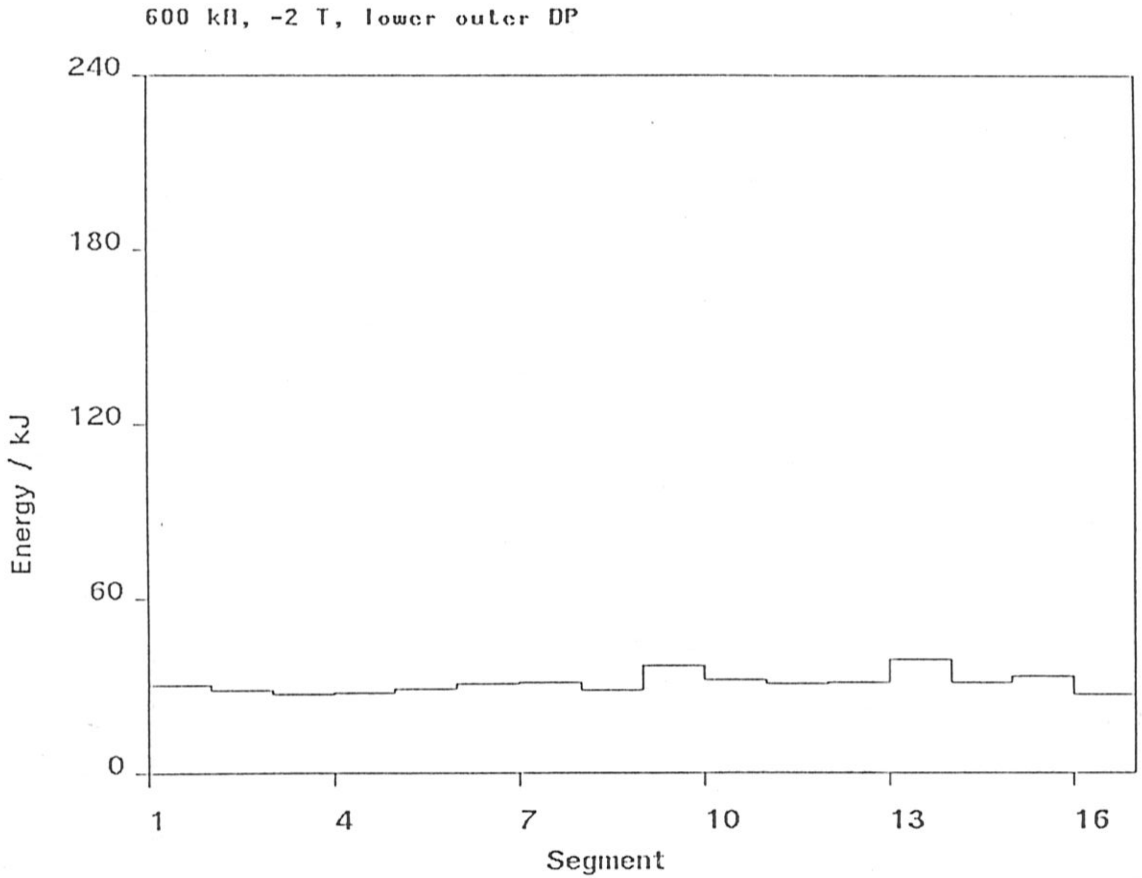
Energy / kJ
1
4
7
10
13
16
Segment

Figure 3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Energy / kJ
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180
120
60
0
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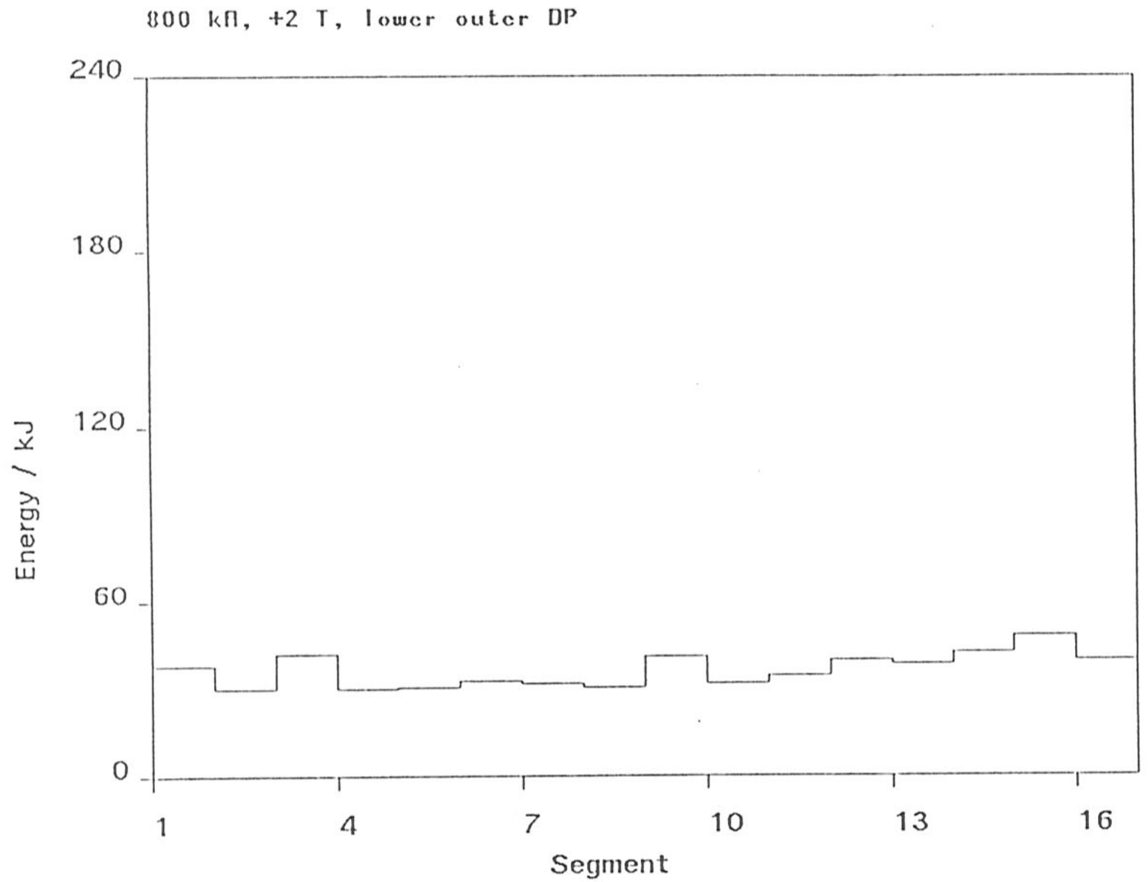
4
7
10
13
16
Segment

Figure 4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7
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13
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Segment

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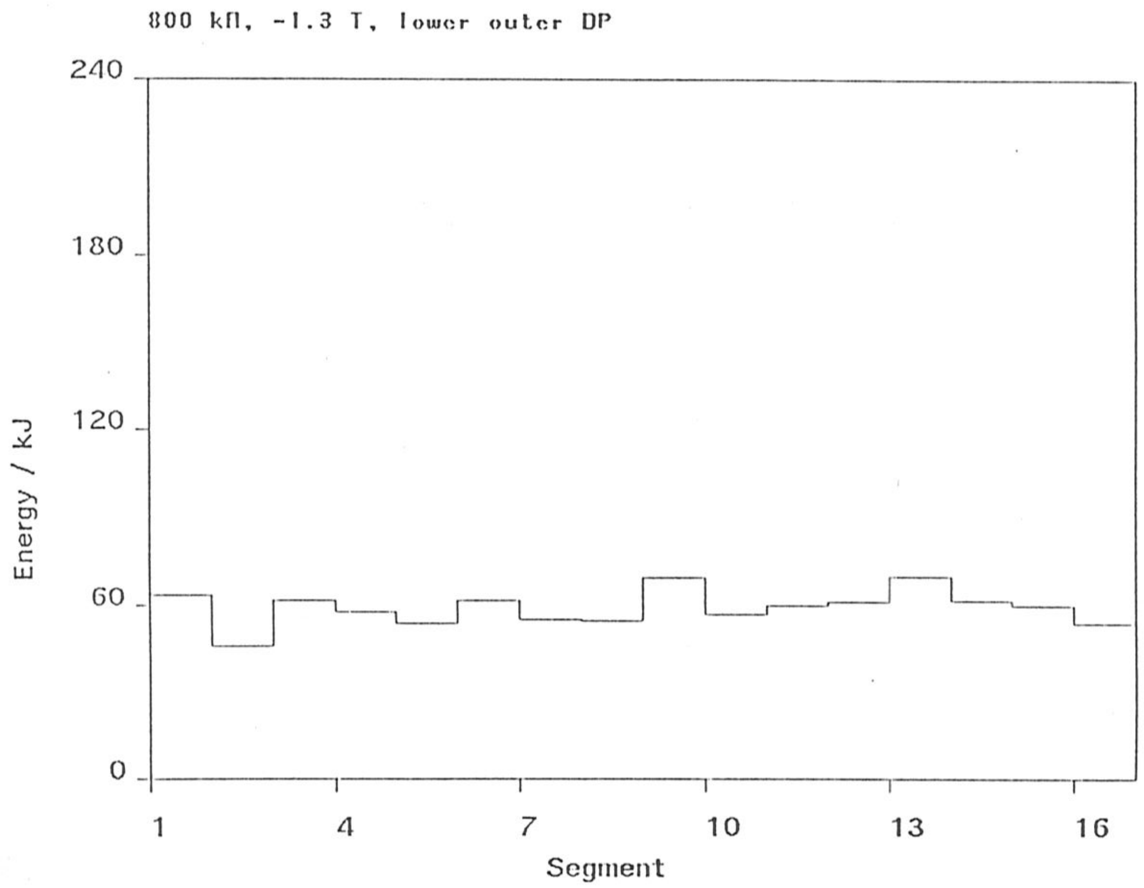
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Energy / kJ
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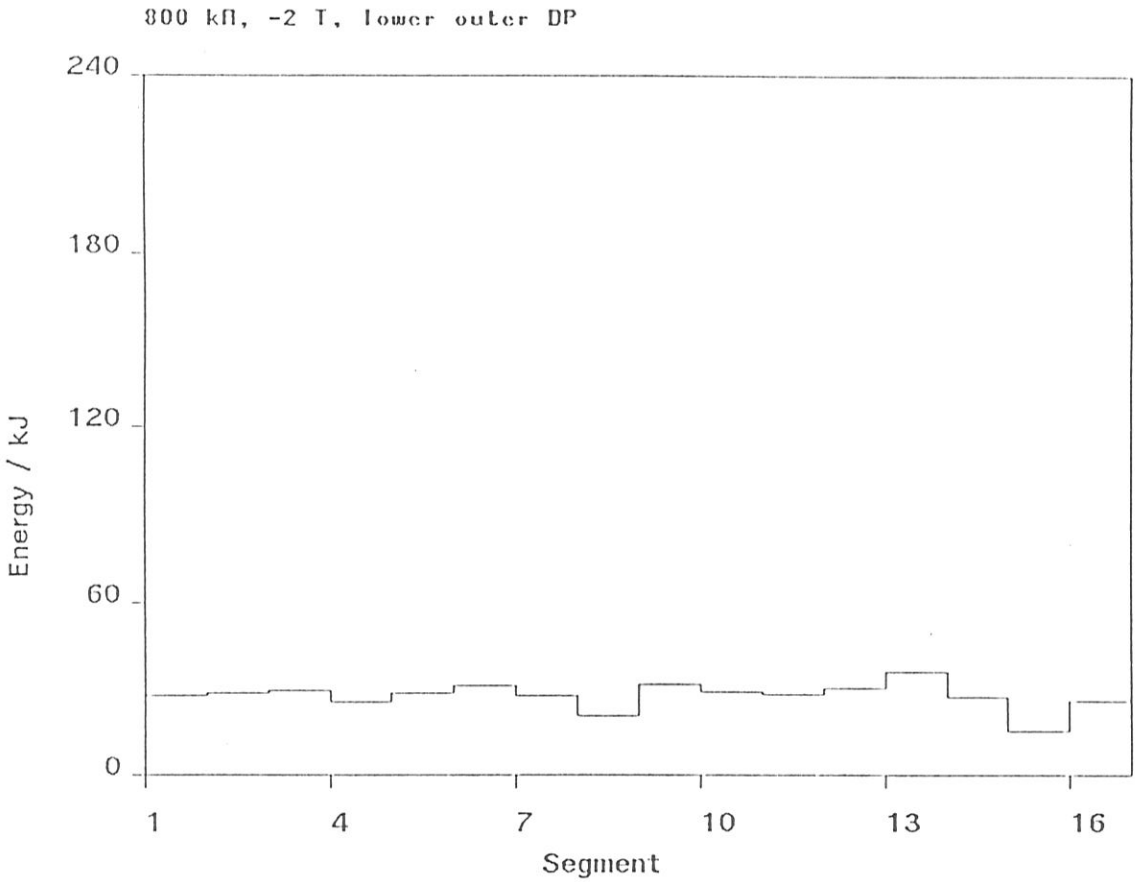
4
7
10
13
16
Segment

Figure 6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Energy / kJ
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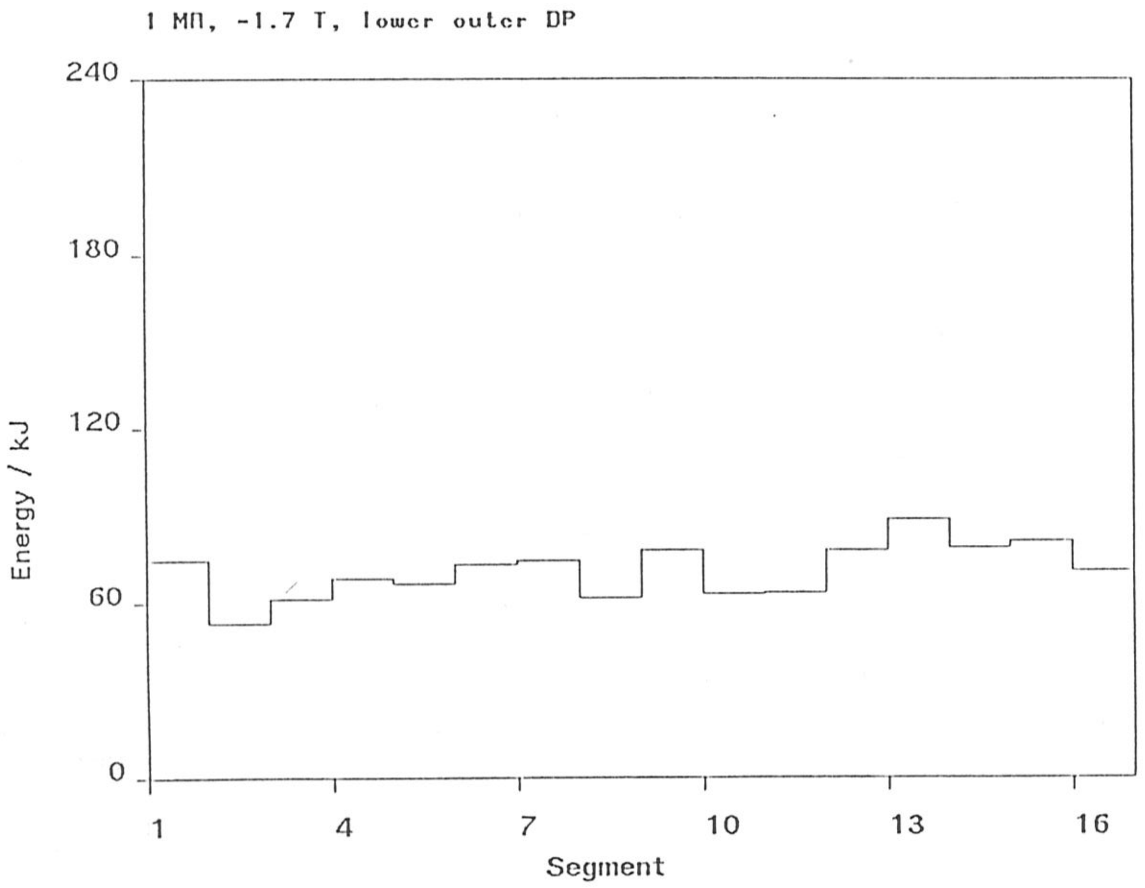
180
120
60
0
1
4
7
10
13
16
Segment

Figure 7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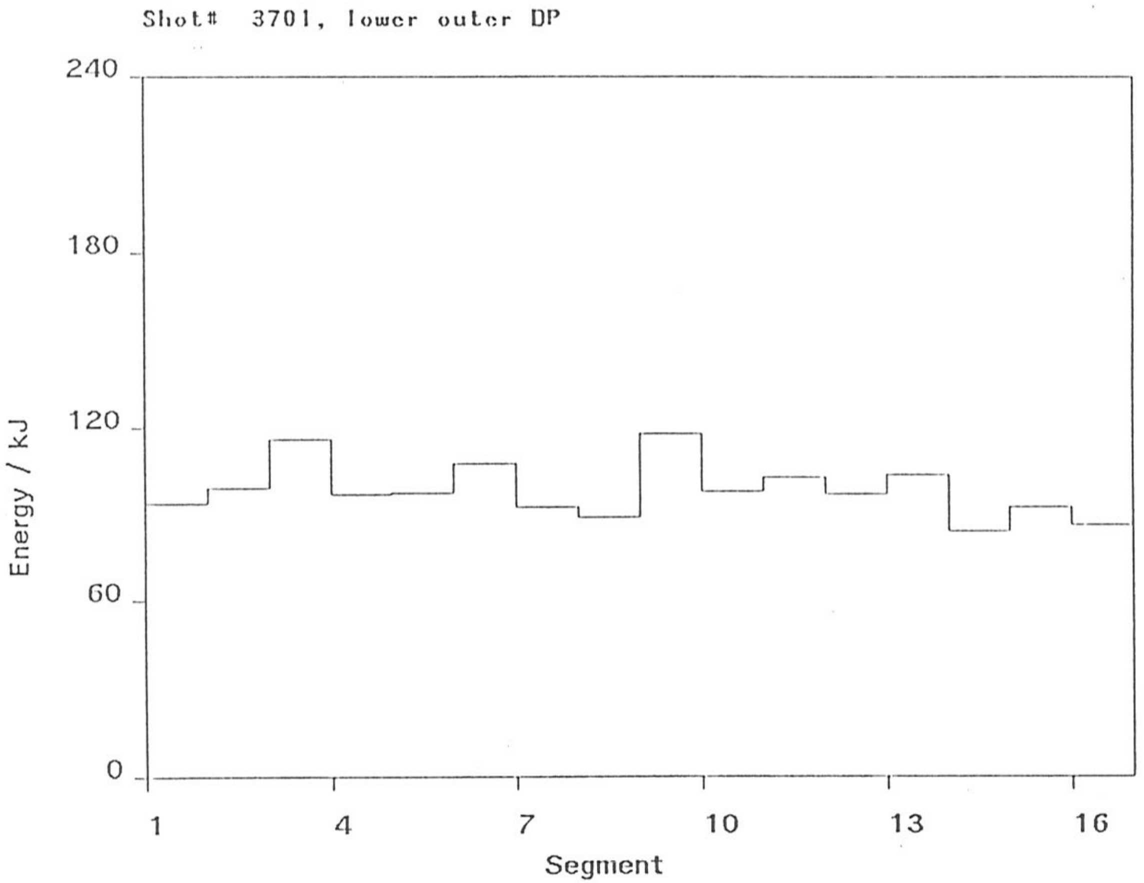
120
60
0
Energy / kJ
1
4
7
10
13
16
Segment

Figure 8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Energy / kJ
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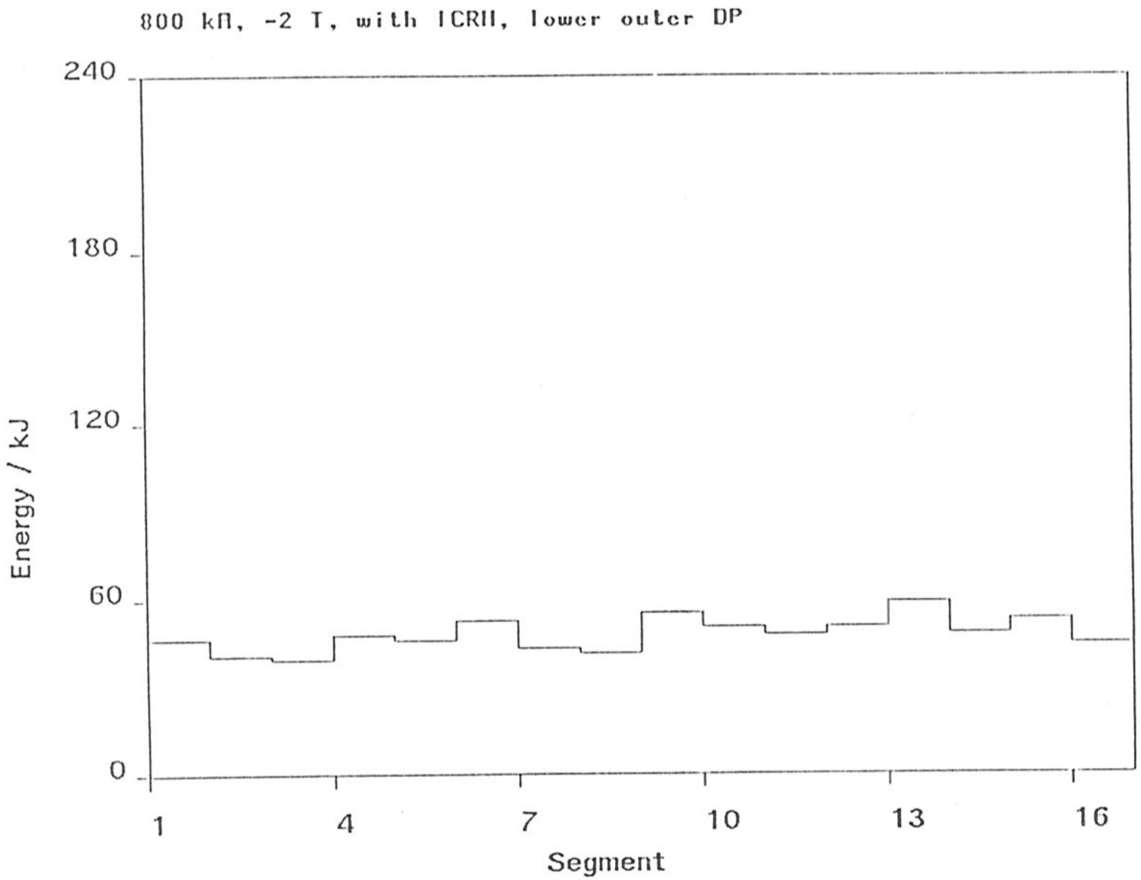
7
10
13
16
Segment

Figure 9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60
0
Energy / kJ
1
4
7
10
13
16
Segment

Figure 10