

Recent Performance Results of the RIT 15 Auxiliary Propulsion Engine

K.H. Groh, N. Kreiling, H.W. Loeb, Th. Schmidkunz, F. Zarnitz

1st Institute of Physics,
Giessen University,
D-6300 Giessen, FRG

Abstract

In the course of 25 years of research, development and qualification work at Radiofrequency Ion Thrusters RIT, different sizes of thrusters have been designed and tested. The standard RIT 10 engine is now facing its first test in space onboard the free-flying platform EURECA, and the operational use of two RIT 10 motors is planned to perform north-south-stationkeeping of ESAs ARTEMIS satellite.

Because of the growing satellite masses and with it the higher thrust requirements, a thrust augmented ion motor, the RIT 15, has been designed by scaling up the standard RIT 10 delivering up to 50 mN thrust using xenon as the propellant. Alternatively, krypton has been tested for the use in ion propulsion.

The performance diagrams of the RIT 15 have been mapped for xenon and krypton and the ion beam characteristics have been studied using the new beam diagnostic equipment. The dependence of the beam parameters on the used propellant and the chosen accel-decel ratio of the high voltages are reported.

1. Introduction

Electric propulsion systems are worldwide a matter of research, development and finally qualification since three decades. The application of electric propulsion for orbit control of geosynchronous satellites promises advantages compared with the conventional chemical propulsion system. Replacing a chemical thruster with a typical specific impulse of 300 sec by an ion engine with a ten times higher specific impulse of typically 3,000 sec results in saving propellant and therefore, extending the satellite lifetime. Hence, it is possible to keep the satellites in position for 10 to 15 years depending on their mass by the use of electric propulsion.¹

This advantage of electric propulsion can be expressed also by savings in the satellites launch mass or by an increase in the payload. Especially for north-south stationkeeping, electric propulsion offers commercial benefits. The thrust requirement of an engine for this application was about 10 mN in the seventies but raised with increasing satellite masses to about 20 mN and for the future generation of communication satellites it tends towards the 50

mN range. Depending on the number of engines installed and the allowed thrusting time per day total thrusting times of up to 10,000 hrs. have to be expected for the ion motors.

At Giessen University the research and development program started in the 60's at a 10 cm diam ion source from which the 10 mN standard engine RIT 10 has been developed. In the course of the 70's, the University of Giessen started activities to scale-up the standard thruster by increasing the diameter of the discharge chamber from 10 cm to 15, 20, and 35 cm. These activities led to the 15 cm engine RIT 15 designed for a thrust level of 20 mN with mercury as propellant.²

While the 20 cm engine has been used mainly for plasmadiagnostic purposes, the large 35 cm diam ion source, RIT 35, has been planned as main propulsion engine aiming at a thrust level of some hundreds of mN. This thrust level is well suited to drive interplanetary probes or other high-energy missions.³ But because of a lack of mission programs and consequently, a lack of money, these activities must be stopped having a laboratory model of the RIT 15 and some experience in the operation of the large RIT 35 engine.

In the early 80's, the European Space Agency, ESA, set up their programs including electric propulsion activities. Now, under ESA contracts the work on electric propulsion systems has been resumed and pushed forward also at Giessen University. ESA decided to perform a space test of a RIT 10 engine onboard the EURECA carrier and later on also to resume the work on the large RIT 35 thruster.

Actually, ESA's technological satellite ARTEMIS is planned to be equipped with an ion propulsion package to perform North-South-Stationkeeping. RIT 10 engines using xenon as propellant are selected from Germany for this task.

After having adapted the small thruster to inert gas propellants, we decided to modify the concept of the mercury RIT 15 and to develop and manufacture an inert gas version of this thruster by inhouse fundings. The laboratory prototype is designed for a nominal thrust level of 20 mN, but thrusts up to 50 mN could be reached using xenon. The performance data of this thruster will be reported for xenon and krypton as well as some results concerning the beam parameters of the engine.

2. Design and Operation of the RIT 15

Since the working mode of the radio-frequency ion motors has been described in earlier papers very often^{4,5} only a short description will be given here due to the differences from the RIT 10 and the Kaufman thrusters (see also Fig.1).

The RIT 15 uses as all RIT engines an ionizer made of an insulating material like quartz which is surrounded by the induction coil. An rf-generator delivers the power, inducing an electrical eddy field in the discharge chamber and thus, sustaining an electrodeless annular rf-discharge. To obtain the best ionization conditions, it is necessary to optimize the ionizer length, the rf-coil geometry, the frequency, and the discharge pressure for different ionizer diameters and propellants.

The RIT 15 prototype, designed for 5 to 50 mN thrust, uses all experiences gained with the RIT 10. The quartz ionizer with 15 cm diam has a xenon-optimized length of 7 cm. The number of turns of the rf-coil has been increased to 16 and the working frequency reduced to 0.76 MHz.

For the ion extraction and thrust production the RIT 15 is equipped with a rugged three-grid extraction system and a separate extraction anode combined with the gas inlet at the ceiling of the discharge chamber.

The first grid, the plasma holder, is made of titanium instead of quartz as for the small standard engine RIT 10. In this case, the plasma holder is floating at the plasma potential which is fixed by the potential of the extraction anode.

The second grid, the accelerator, is made of graphite as for all RITs because of its low sputtering rate for ion impingement and it is usually at negative high voltage. The grounded third grid, the decelerator, is made of stainless steel and provides a homogenous potential across the ion beam corresponding to the potential of this grid.

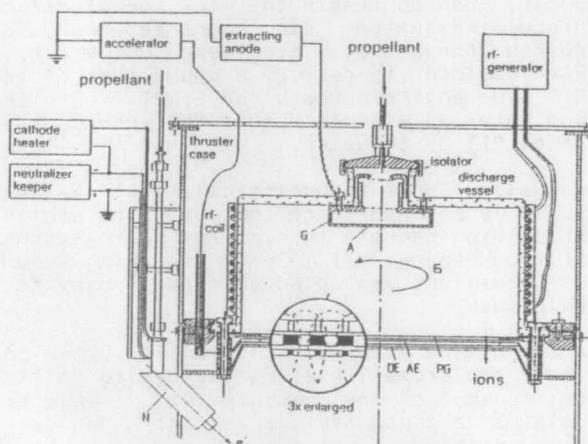


Fig.1: Cross-section of RIT 15 ion thruster (G= gas inlet; A= anode; PG= plasma holder; AE= accel electrode; DE= decel electrode; N= neutralizer)

The RIT 15 engine uses a flat grid system as the smaller RIT 10 motor but a dished grid system would be preferable because of its superior stability especially under thermal load at higher thrust levels.

All RIT engines use the same grid geometry. The diameter of the grid borings is 4 mm for the plasma holder, 2 mm for the accel grid, and 4 mm for the decel grid. The distance of the axis of two borings is 5 mm. The space between the grids is 1 mm. Referred to the above geometry, a total extraction voltage of about 3 kV to 3.5 kV must be applied for correct focusing of the ion beam. The number of extraction borings which is also given by the geometrical factors is 571 for the RIT 15 yielding an open area ratio of 51% referred to the real extraction surface.

A conventional plasma bridge neutralizer taken from the RIT 10 delivers electrons for the neutralization of the ion beam and the start of the main discharge⁶. The hollow cathode was operated only with xenon using a separate feed line. However, due to the sensitivity of the electron emitter to oxygen a special oxygen trap is used in this feed line of the neutralizer. Otherwise, the lifetime of the hollow cathode is very short.

During the start-up procedure of the main discharge, the accel grid is biased at about 100 volts positively in order to attract electrons and inject them into the discharge chamber. Typically, the neutralizer discharge is sustained at flow rates of about 0.04 mg/s to 0.05 mg/s at a discharge power of about 7 watts. A special bias voltage to inject the electrons into the ion beam has turned out not to be necessary.

Presently, the laboratory prototype of the RIT 15 has a case diameter of 22 cm and is 18 cm in length. The thruster weight is 2.5 kg but all values are not yet optimized. The cross section in Fig.1 demonstrates the set up of this thruster on principle.

The RIT 15 rf-thruster has the same conceptual advantages compared with the dc-bombardment type of thruster:

- simple, rugged and reliable design and construction
- less power supplies and all at ground potential
- less propellant control units
- simple and reliable control loop
- no doubly charged ions in the discharge and consequently in the beam
- due to the absence of discharge electrodes all related problems of the dc-bombardment thrusters are avoided from the outset

These advantages of the RIT principle must be paid by a little bit less efficient ionization and some eddy current losses which finally result in a few percent lower total efficiency compared to the dc-bombardment thruster.

The only lifetime limiting factor is sputtering of the accel grid forming slowly conductive carbon layers on the walls of the ionizer. This effects finally a shielding of the rf and therefore, requires a somewhat higher rf-power consumption.

3. Performance of the RIT 15

Until end 1989, the RIT 15 has been performance mapped in the big JUMBO test facility of Giessen University using xenon as the propellant. In this facility the engine could be tested up to the full thrust level of 50 mN under adequate background pressure conditions and has demonstrated that the design goal could be verified.

In the beginning of this year, the engine has been put again into the test chamber with the aim to determine the performance for krypton as the propellant and to examine the ion beam characteristics by means of the now available beam diagnostics.

Since mercury is no longer accepted as an ion thruster propellant because of its contamination problems and replaced by the inert gas xenon, the discussion arose that xenon is extremely expensive and the availability may be limited. Indeed, xenon is received from the liquefaction of air as krypton, too, but the proportion of krypton in the atmosphere is about 14 times higher than that of xenon. This is reflected directly in the price and also in the more or less unlimited availability for ion propulsion purposes and therefore, krypton seems a possible propellant candidate.⁷

From the physical point of view, krypton differs not so much from xenon. The ionization energy is somewhat higher and the mass number is lower. This results of cause in a reduction of the thrust of 20% at the same beam current and beam voltage. In Table 1 some typical data of xenon and krypton are compiled.

Table 1:

	xenon	krypton
Atomic number	54	36
Mass number	131.3	83.8
Density of gas, kg/m ³	5.9	3.8
critical pressure, bar	58.4	55.0
critical temperature, K	290	210
portion in atmosphere, vpm	0.08	1.1
1. Ionization energy, eV	12.1	13.9

The performance mapping on the RIT 15 has been carried out using the new data acquisition system of the JUMBO test facility. This system measures all relevant thruster data as there are ion beam and drain current, the consumed rf-power, the propellant flow of the thruster and the neutralizer, and the positive and negative high voltage. In addition, an online data evaluation is installed which shows on a second screen directly the discharge characteristics (this is rf-power consumption versus the mass flow) of the tested ion source. This system reduces the time needed for ion thruster characterization significantly and because of the use of laboratory power supplies it is possible to test different sizes of thrusters with the same equipment.

Fig.2 gives the discharge characteristic of the RIT 15 ionizer for xenon, depicting the consumed rf-power as a function of the propellant flow rate with the ion beam current as parameter which runs from 150 mA up

to 650 mA. The dashed line represents the maximum total efficiency of the thruster which is the product of mass efficiency times electric efficiency. It varies from 45% up to nearly 60% with increasing ion beam current.

Both efficiencies are graphed in Fig.3, one against the other for beam currents from 150 to 650 mA which corresponds to thrust levels from 10 to 50 mN. It turns out that high electric efficiencies must be paid by a lower mass utilization and, on the other side, extreme high mass efficiencies are combined with poorer electric efficiencies which is a well known fact for the rf-ion thrusters. The graphs are calculated for a beam voltage of 2 kV and include all losses also for the neutralizer.

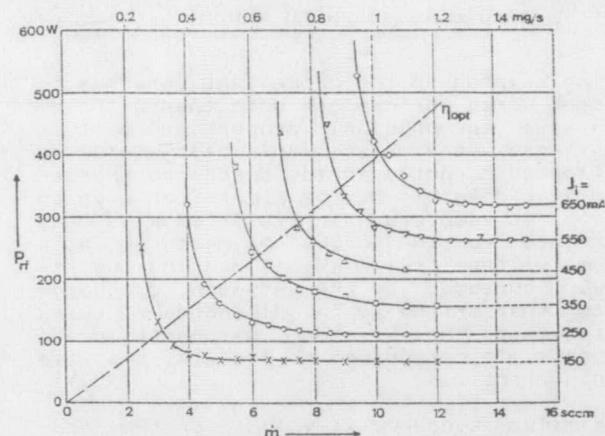


Fig.2: RIT 15 ionizer discharge characteristics for xenon

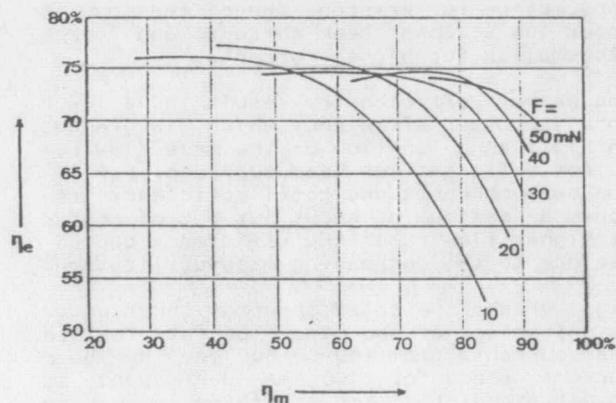


Fig.3: Electric versus mass efficiency of the RIT 15 for xenon and thrust levels from 10 to 50 mN

Fig.4 finally gives the total thruster input power as a function of the propellant consumption for thrust levels from 10 to 50 mN. The maximum thrust of 50 mN is delivered by a beam current of 0.67 A at a beam voltage of 2 kV. This results in an ion velocity of 55 km/s and a specific impulse of 4,350 sec. The total power consumed amounts to about 1.8 kW which gives an electrical efficiency of 73%. A propellant utilization of 81.5% results from a working point at 11 sccm total flow plus 0.5 sccm for the neutralizer ending up at a total thruster efficiency of 59.5% for 50 mN thrust.

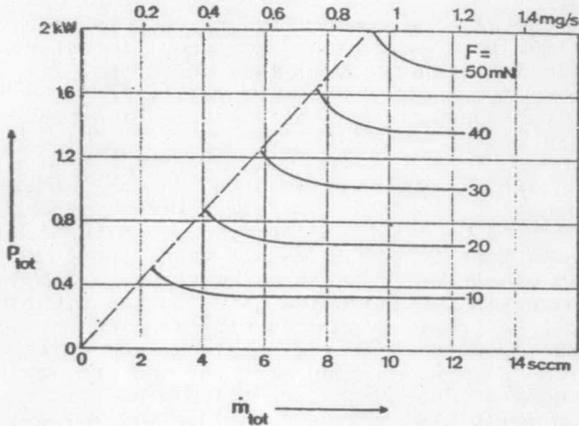


Fig. 4: Total thruster input power versus propellant consumption for different thrust levels with xenon

Using krypton as the propellant one has to expect worse performance data than with xenon due to the physical properties of this inert gas (see also Table 1). This is reflected directly in the discharge characteristic diagram of the RIT 15 for krypton which is depicted in Fig. 5 for ion beam currents from 100 to 500 mA measured at a beam voltage of 1.5 kV. Comparing the rf-power consumed by the krypton discharge with that of the xenon discharge it turns out that the krypton discharge needs roughly 15% more power to produce the same ion current.

A similar tendency is valid for the propellant consumption. Looking for the working point at maximum total efficiency which is indicated in Fig. 5 by the dashed line one finds also a higher propellant consumption for krypton. The difference is about 10% at lower beam currents and becomes smaller for higher currents.

The weaker efficiencies result in a lower total thruster efficiency which is graphed in Fig. 6 as a function of the mass flow rate for different ion beam currents. For all ion beam currents the total efficiency reaches a maximum of about 50% but of course at higher flow rates the efficiency decreases due to the decreasing mass utilization.

Fig. 7 graphs the total thruster input power as a function of the mass flow rate for ion beam currents from 100 to 500 mA. The beam current steps of 100 mA correspond to thrust steps of 5 mN beginning with 5 mN and ending with 25 mN. The thrust levels are referred to a beam voltage of 1.5 kV which results for krypton in an ion velocity of 58 km/s reaching a specific impulse of 4,700 sec or 46,800 Ns/kg. The total thruster input power ranges from 200 watts for a 5 mN level up to 1,000 W for the 25 mN thrust level.

Referred to the xenon working point of the RIT 15 at 2.0 kV beam voltage and 650 mA beam current, a maximum thrust of 40 mN can be expected for krypton under the same working conditions. This corresponds to a 20% thrust loss compared with xenon due to the difference in the atomic weight of both gases.

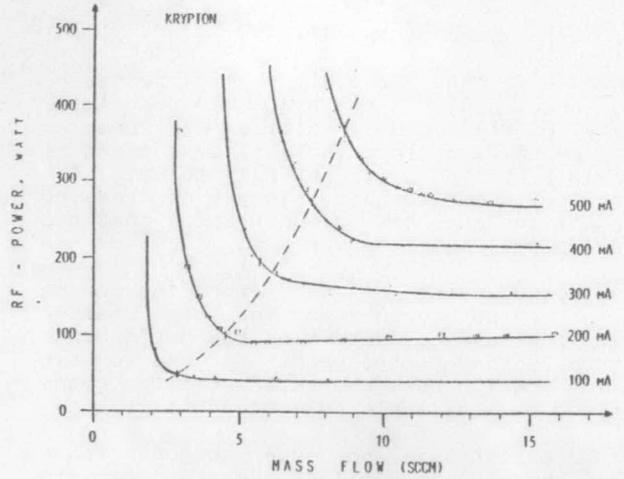


Fig. 5: Ionizer discharge characteristics of the RIT 15 laboratory prototype for krypton as propellant

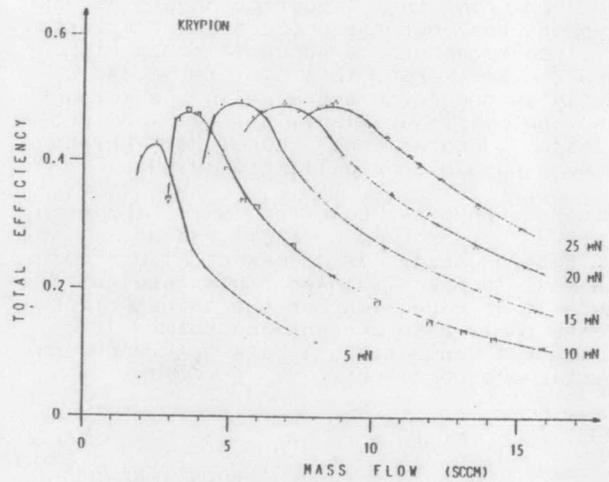


Fig. 6: Total efficiency of the krypton RIT 15 versus the mass flow rate for five beam currents or thrust levels from 5 to 25 mN

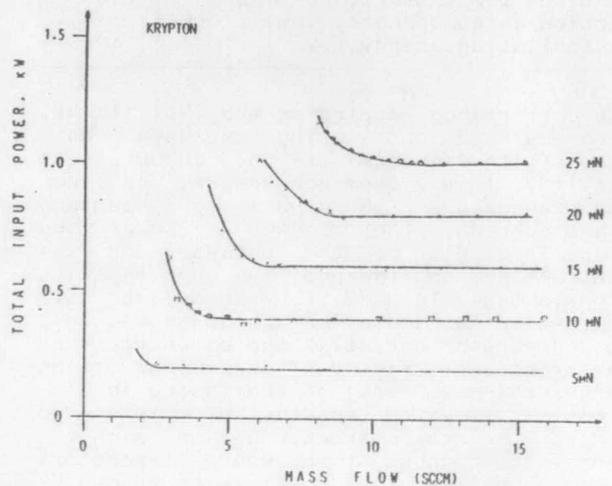


Fig. 7: Total thruster input power for krypton versus the propellant consumption for different thrust levels of the RIT 15 from 5 to 25 mN

The performance mapping of the RIT 15 using krypton as the propellant has yielded very encouraging performance data. The thruster can be operated with krypton as stable as known already from xenon operation. But it turned out that the thermal load of the grid system becomes critical especially for high beam currents. The limits of the flat grid design seem to be reached now and a further model of a RIT 15 should be equipped with dished grids for better thermal stability.

A further test serie with the RIT 15 motor aimed at beam diagnostic measurements. For this purpose, the RIT 15 has been operated with different propellants as xenon, krypton, argon, and nitrogen. Moreover, the beam voltage has been varied between 500 and 2,000 volts in steps of 250 volt by changing the accel-decel ratio of the high voltages but keeping the ion extraction voltage constant at 3.0 kV. This means for the negative high voltage a variation between 2,500 and 1,000 volts.

As expected, the ion beam becomes the broader the smaller the accel-decel ratio is. The relations are illustrated in Fig.8, where the beam divergence is graphed versus the beam voltage. Parameter is the used gas.

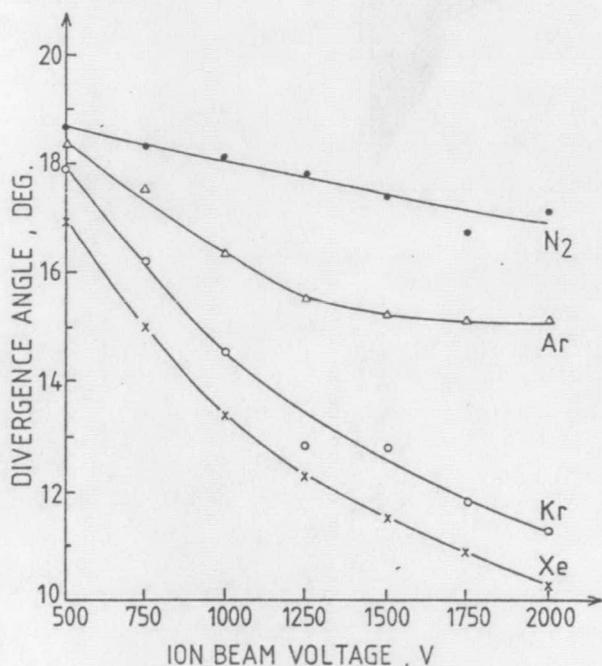


Fig.8: Divergence angle of the RIT 15 ion beam for different beam voltages and different propellants

It is obvious that the ion optics of the grid system gives the best results for high beam voltages as it was developed for. The divergence of the beam increases rather significantly for beam voltages below 1,250 volts. If low ion beam velocities are required it is necessary to adapt the extraction grid system by reducing the gap between plasma holder and accel grid.

The grid geometry turns out to be well suited for heavy propellants as xenon and krypton (it was originally designed for mercury). But for lighter gases as argon or nitrogen the beam will not be focused by the given grid geometry which, on the other hand, is not relevant for ion thruster applications.

Fig.9 is a serie of 4 three-dimensional ion beam profiles of the RIT 15 for different ion velocities starting with 500 volts and a rather broad beam and going in steps of 500 volts up to 2,000 volts at which a small well focused beam is obtained.

4. Conclusions

The technology of radio-frequency ion thrusters has been studied and developed in Germany since nearly three decades and has proved its capability in numerous tests and the small NSSK engine RIT 10 has passed all qualification tests successfully.

The more powerful thruster RIT 15 is directly derived from the RIT 10 by scaling up the ionizer. All experiences of the RIT 10 development have been considered in the design of the RIT 15 and RIT 10 components have been used if possible as e.g. the plasma bridge neutralizer.

The present laboratory model of the RIT 15 represents a status from which an industrial redesign can be started in order to develop an engineering model. The RIT 15 has proved its excellent performance and is well suited as a north-south stationkeeping engine for communication satellites.

Acknowledgement

The reported work is part of the Diploma Thesis of the coauthors N. Kreiling and Th. Schmidkunz. The support of F. Zarnitz is gratefully acknowledged.

References

- 1 H. Bassner, D. E. Koelle, IAF-Paper 87-496, Brighton, UK, 1987
- 2 J. Freisinger, S. Reineck, E. Rumpf, H.W. Loeb, AIAA-Paper 76-1038, Key Biscayne, 1976
- 3 E. Stuhlinger, H. Fechtig, E. Igenbergs, H. Loeb, Journ. Brit. Interplan. Soc., 39, pp. 273-281, 1986
- 4 H.W. Loeb, J. Freisinger, K. Groh, W. Pinks, P. Schafer, R. Schmiele, AIAA-Paper 76-1037, Key Biscayne, 1976
- 5 H.W. Loeb, J. Freisinger, K.H. Groh, A. Scharmann, IAF-Paper 88-258, Bangalore, India, 1988
- 6 S.E. Walther, K.H. Groh, H.W. Loeb, AIAA-Paper 78-706, San Diego, USA, 1978
- 7 R. Welle, AIAA-Paper 90-2589, Orlando, USA, 1990

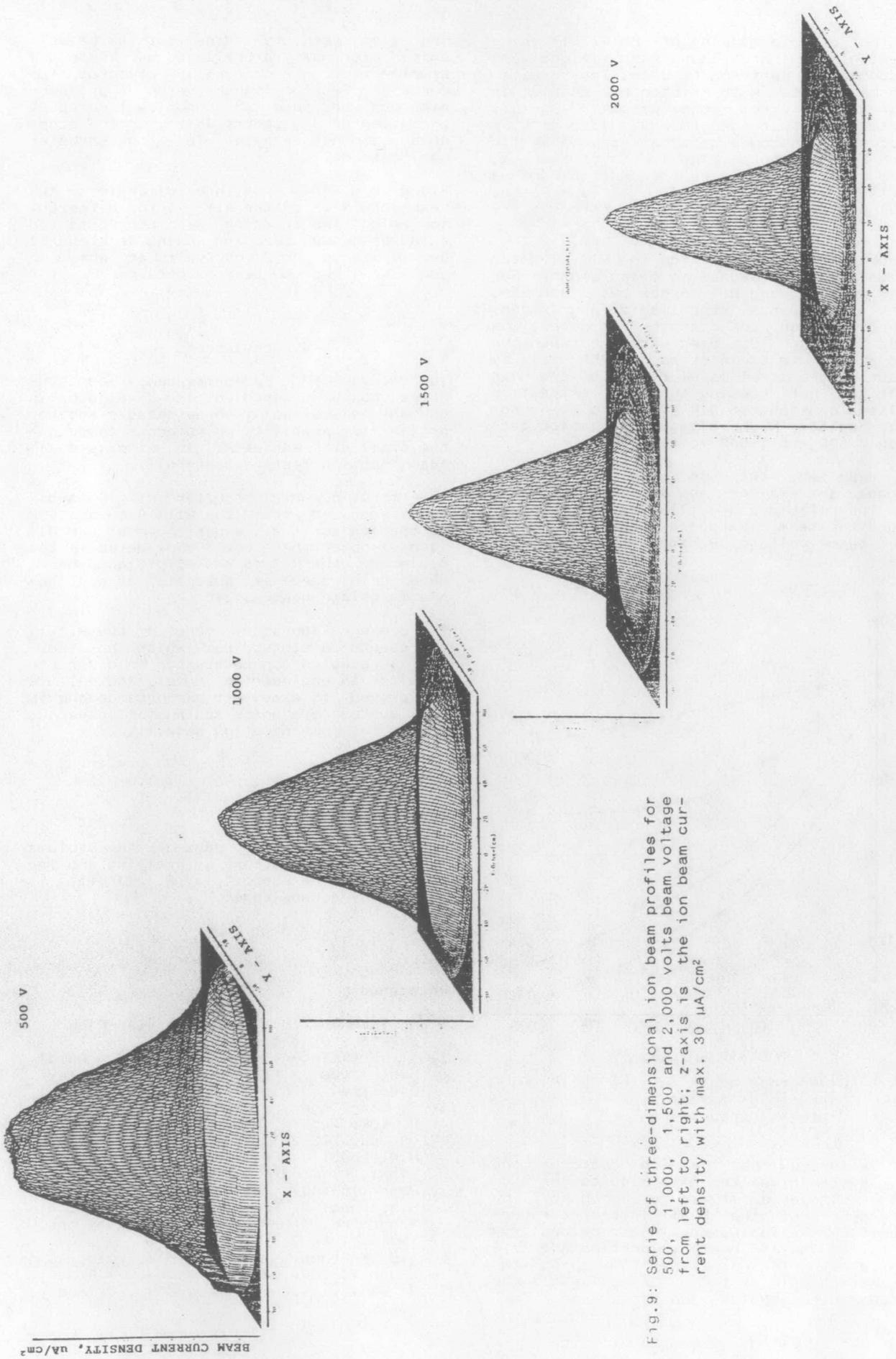


Fig.9: Serie of three-dimensional ion beam profiles for 500, 1,000, 1,500 and 2,000 volts beam voltage from left to right; z-axis is the ion beam current density with max. 30 $\mu\text{A}/\text{cm}^2$