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Technical Note

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Information about the first Elekta Precise® accelerator installed in Poland

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Authors' Contribution:
- **A** Study Design
- **B** Data Collection
- **C** Statistical Analysis
- **D** Data Interpretation
- **E** Manuscript Preparation
- **F** Literature Search
- **G** Funds Collection

Summary

Background The first medical linear accelerator manufactured by Elekta Limited was installed and put into clinical operation in Poland in 2004.

Aim The aim of this article is to show the performance of the accelerator installed in the Białystok Centre of Oncology and configured in the version Elekta Precise®.

Materials/Methods The study presents the most important features of the system as well as the results of dosimetric measurements for photon beams of nominal energies 6 and 15MV and electron beams of energies 6, 9, 12, 15, 18 and 22MeV, as set for this machine. The results of some acceptance tests and clinical performance checks are presented and discussed.

Results/Discussion First experience with accelerator at work gathered within a period of one year has shown very good stability of basic parameters of the machine. Most performance parameters were exceptionally good: reproducibility: <0.1%, proportionality: <0.5%, stability throughout the day: for photons (<0.2%), for electrons (<0.5%), angular dependence: maximum difference was 0.6% for photons and 0.8% for electrons with very good uniformity of electron beams (<105%).

Conclusions Dosimetric measurements demonstrated the agreement of checked parameters with the manufacturer's specification and IEC standards as well as national recommendations. Medical accelerator Elekta Precise Treatment System (TM) demonstrated its full usefulness for clinical applications. The machine parameters and functionality meet the requirements of the modern radiotherapy facility.

Key words **linear accelerator • Elekta Precise • radiotherapy**

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Background

The huge progress achieved in the last ten years in radiotherapy was enabled mainly by the development of particle acceleration techniques and information technology. At present the linear accelerator, accelerating electrons with the help of the electric component of a high frequency electromagnetic field, is an essential tool of modern radiotherapy. Most medical accelerators used in Polish cancer hospitals were manufactured and installed by the Polish company ZdAJ Świerk and two world leading manufacturers of such equipment, Siemens and Varian. At the end of 2003 the third widely recognized linac manufacturer introduced its Elekta Precise Treatment System™ in Poland – a radiotherapy line with accelerator and accompanying equipment was installed in the Białystok Centre of Oncology.

Aim

This work describes the first Elekta Precise Treatment System™ installed in Poland as well as presents the results of some measurement results. The main goal of the authors was to show the technical specifications of the accelerator and dosimetric performance of the Elekta Precise, taking into consideration the stability of the performance within one year of clinical work.

Technical Specifications of Accelerator Elekta Precise® [1,2]

Accelerating structure and construction of the head of Elekta Precise®

Construction of the head of Elekta Precise® accelerator is shown in Figure 1, and the accelerating structure is shown in Figure 2.

Elekta's solution of accelerating structure with travelling waveguide is unique on the market. The accelerator is powered with a high frequency microwave tube working in band S of the frequency set for about 3GHz, corresponding to the wavelength of about 10cm. The source of microwaves is a fast tune magnetron, whereas the electrons are produced by an electron gun of the diode type.

The conversion of accelerated electrons bundle to photon beam occurs in the material of the tungsten target. The resulting X-ray beam passes through a thin metal window in the target section and then through a hole in the primary filter. Then the photons are collimated by the primary rotatable collimator: high energy X-rays through port 1 containing the differential filter, low energy X-rays through port 2 which is empty. Then the photon beam is flattened by the secondary filter dependent on the energy selected. The multisection ionization chamber connected with the dosimetry system is mounted under the filter, providing the stabilization of beam parameters and dose and dose rate measurements in two dosimetry channels. The monitor chamber is protected by an aluminium plate, which shields the chamber from the unwanted contribution of backscatter radiation.

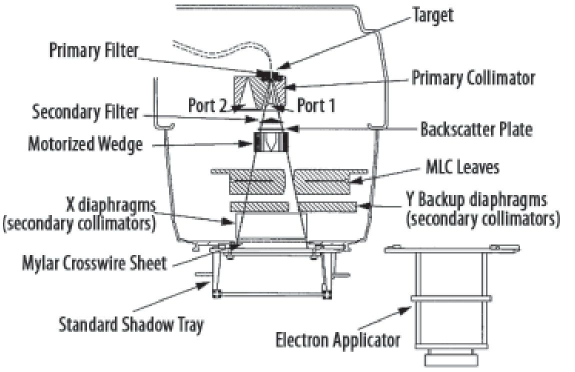

Figure 1. Construction of the head of Elekta Precise® accelerator [1].

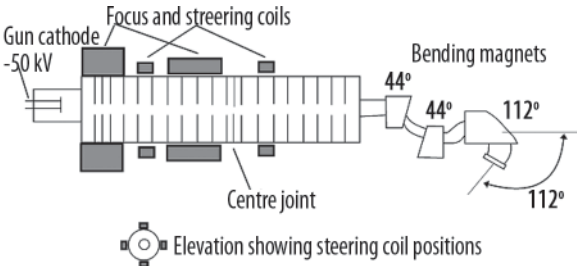

Figure 2. Accelerating structure of Elekta Precise® [2].

A layout of moving jaws collimating the beam is situated in the bottom part of the head. Close to the target is a multileaf collimator, then the backup jaws X, which follow the last leaf in the leafbank (trailing leaf). Below the backup jaws X there is a typical set of Y jaws. A shadow tray assembly with shielding blocks can be optionally used.

In the electron mode the beam passes through a thin metal window in the target section. Then

Table 1. Basic characteristics of the Elekta Precise® collimator parts [1].

Name of collimator part	Collimator setting in cm (min/max)	Material
X (MLC)	–12.5/20.0	Tungsten with the addition of lead
X (backup)	–12.5/20.0	Tungsten
Y	0.0/20.0	Tungsten

the beam is filtered through an electron scattering material dependent on the energy selected – primary filter – and collimated by the rotational collimator through port 2, which is empty. Further on the electron beam is scattered by the secondary profile filter (low Z number) designed to interact with different energies particles. Then the beam passes through the collimator assembly. The X and Y jaws fit automatically to the chosen applicator, while the MLC leaves are opened to the maximum field size. The applicator with the coded end frame is the last element modifying the electron field. Applicators are equipped with standard end frames defining the size of field at the distance of 95cm from the source. Maximum field size for the electron beam at this distance is 25×25cm (at the distance of 100cm from the source the field is bigger). Elekta Precise® beam shaping accessories also include circular (tube) electron applicators with steel inserts of diameter 2, 3, 4 and 5cm.

As mentioned above the multileaf collimator forms the shape of the photon beam. The MLC installed in Elekta Precise® accelerator working in Białystok consists of 80 leaves. Their width at isocentre is 1.1cm. The additional shielding of the field edge consists of backup jaws X. Both pairs of jaws – X and Y – operate in the asymmetrical mode. Information about the movement range of all collimator parts and the material they are made of is shown in Table 1. More detailed information regarding Elekta multileaf collimator with dosimetric characteristic of MLC can be found in the papers by Huq et al. [3] and Haryanto et al. [4].

The bottom surface of the leaves is situated at a distance of 37.3cm from the source. The clearance below the head without the tray assembly is 45.2cm. The head is furnished with a motorized wedge with wedging angle 60 degrees, which can be automatically put into the beam according to the treatment plan. During field irradiation the planned combination of the wedged and non-wedged beams allows the beam to be wedged at an angle varying from 0 to 60 degrees. The unique design of the therapy table assures very precise and smooth movements. Elekta Precise® accelerator can operate with an electronic portal system for patient position verification. In the Białystok Centre of Oncology the EPID option iView GT based on underside phosphorous-coated detector with special arrangement of CCD cameras allows images to be obtained of the size 410×410mm, 1024×1024pixels.

The medical accelerator installed in the Białystok Centre of Oncology enables radiotherapy with photon beams of energy 6 and 15MV* and electron beams of energy 6, 9, 12, 15, 18, 22MeV.

Beam Bending and beam focusing system

The good quality of the beam in the Elekta Precise® accelerator is achieved by the special construction of the beam focusing and bending system. The magnetic field assembly for the beam transport consists of the set of focusing solenoids and two pairs of centering solenoids put around the accelerating structure. Outside the accelerating structure additional bending magnets are installed. The solenoids produce a perpendicular magnetic field, which is dynamically controlled by the dosimetric system measuring the beam parameters. Signals received from the sections of the cylindrical chamber are monitored and analysed by the processor. It allows for determination and necessary corrections of beam homogeneity in real time.

On the end of the Elekta Precise® acceleration structure several electromagnets form the beam bending system of slalom type (Figure 2). The first electromagnet works as the energy analyser. The value of the magnetic field generated by this electromagnet is tuned to fit the energy of electrons to the expected mean value. Then the beam is focused in two perpendicular planes of the second magnet. The third magnet deflects the beam in the vertical plane. The resulting electron beam of a diameter of about 2mm hits the target.

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[*] In accordance with the contemporary trend in the literature we use the expression "photon beam energy of 6 MV" meaning the value of maximum accelerating potential of 6MV, nominal energy for accelerated electrons of 6MeV.

The structure of the accelerator permits the independent adjustment of beam parameters – homogeneity, symmetry – for each energy. Such a solution prevails in comparison with the structures in which the choice of parameters is determined for one chosen energy and the parameters of the other beams result from this particular setting. However, this solution is very demanding for the Elekta service engineers. They have to perform the appropriate adjustment for each energy in question. The installed software enables the user to perform monitoring of beam deflection and fast checking of therapy beam parameters. Thanks to this tool the user can avoid very time-consuming dosimetry measurements in the water phantom. More technical information about the design of linear accelerators can be found in the books of Sharf & Siebers [5] and Van Dyk [6].

MATERIALS AND METHODS

Acceptance tests were made before handing the accelerator over for clinical use. The acceptance tests were compliant with national recommendations concerning teletherapy equipment [7]. Beam quality parameters of photon and electron beams were determined on the basis of the IAEA TRS 398 report [8]. Measurements of percent depth doses and beam profiles were performed using the MP3 beam analyser.

In accordance with the IAEA TRS 398 report [8] the beam quality index ($TPR_{20,10}$) for high-energy photons was calculated from the equation:

$$TPR_{20,21}=1.2661PDD_{20,10}-0.0595$$

where:
$TPR_{20,10}$ – tissue phantom ratio that is the ratio of the absorbed dose at depth of 20cm to the dose at depth of 10cm in a water phantom measured with a constant source-to-chamber distance of 100cm and a field size of 10×10cm^2 at the plane of the chamber,
$PDD_{20,10}$ – ratio of percentage depth doses at depth of 20cm and depth of 10cm for the field size of 10×10cm^2 at the phantom surface with an SSD of 100cm.

The beam quality index for electrons is the half value depth in water R_{50}. This index was calculated from the following equation:

$$R_{50}=1.029R_{50jon}-0.06\ [g/cm^2];\ (R_{50jon} \leq 10g/cm^2)$$

where:
$R_{50\ jon}$ is the depth in water (in g cm^{-2}) at which the ionization current is 50% of its maximum value; we measured this quality factor for the applicator of 25×25.

Parameters of electron beams and percent depth doses for photons were measured with a parallel Markus chamber, whereas the photon profiles were determined with a PTW cylindrical chamber of 0.125cm^3.

The values of penumbra, symmetry and homogeneity of photon and electron beams were also established. Symmetry and homogeneity were outlined using the tool functions of Mephysto software based on the IAEA TRS 277 report [9]. The field area for calculations covers 80% of the whole field on both sides of the central axis for photons, whereas the electron field is reduced by 1 cm within 90% field boundary. Conditions of measurements for photon beams: depth 10cm, SSD=90cm; for electrons the depth of measurements was equal to the depth of maximum dose, SSD=100cm.

$$Symmerty=\left(\frac{D(x)}{D(-x)}\right)_{\max}\cdot 100\%$$

where:
D(x) – dose in the x point,
x and -x of the distance from the axis of the bundle.

$$Homogenity=\frac{P\max}{P\min}\cdot 100\%$$

where:
Pmax and Pmin are the highest and lowest value, respectively, in dose distribution in the region of measurements.

Stability throughout a day and long-term (one-month) stability were determined. The stability was measured for all energies and beam types in the PMMA phantom for 10×10 cm^2 field, at SSD=100cm, at the depth of 1.7cm using the Farmer type ionization chamber and PTW UNIDOS electrometer.

Stability within a day was determined by means of measurements performed in time intervals of 8 hours. Stability throughout a day was defined on the basis of national recommendations [7].

Angular dependence of the output factor was established. This relation was measured with a Farmer type ionization chamber with PMMA cap. For measurements of the photon beam the

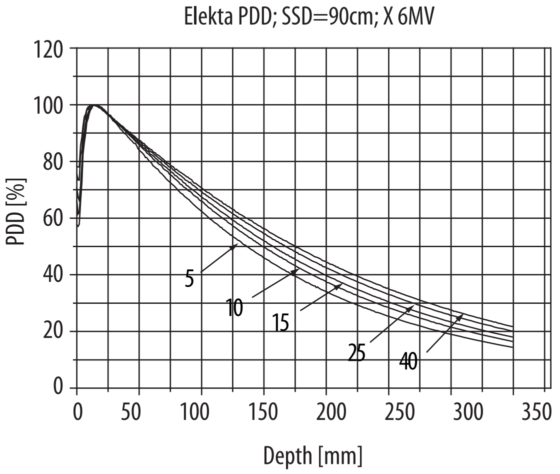

Figure 3. Percent depth dose curves in water for 6MV photon beam and various square fields from 5 to 40cm.

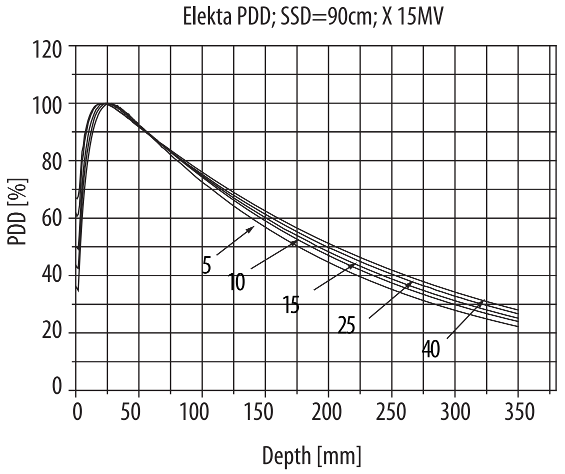

Figure 4. Percent depth dose curves in water for 15MV photon beam and various square fields from 5 to 40cm.

chamber was placed on a block tray, whereas for the electron beam the chamber was attached to the electron applicator of 6×6.

Proportionality (P) and reproducibility (R) were checked and determined in accordance with the national recommendations [7] and performed in the same setting as the stability measurements.

We checked linearity of dependency of the MU (number of monitor units) on the resultant dose in the broad range of MU. The deviation between measured values of doses and fitted data was evaluated. More information about this test can be found in the References [7].

Reproducibility was determined using the following equation:

$$R=\frac{100}{\bar{O}}\sqrt{\sum_{i=1}^{n}\frac{(\bar{O}-O_i)^2}{n-1}}\ [\%]$$

where:
O_i – the value of output for the beam in one of the measurements [Gy/MU],
$\bar{O}$ – the mean value of output for all measurements [Gy/MU],
n – the number of measurements; in our measurements n=5.

Measurements of relative dose rate were performed in the reference conditions, namely:
Photons: SSD=90cm, depth=10cm; reference field of 10×10cm^2,
Electrons: SSD=100cm, depth equal to reference depth, reference applicator of 10×10,

OF was calculated from the following equation:

$$OF=\frac{W(a)}{W(ref)}$$

where:
OF – relative output dose rate for square field of size “a”,
W(a) – output dose rate for field “a”,
W(ref) – output dose rate for reference field.

RESULTS

Photon beam parameters

Beam quality factors for photons of nominal energies 6 and 15MV were respectively 0.680 and 0.758. Depth of dose maximum for 6 and 15MV and square field of 10×10cm^2 was 1.5cm and 2.6cm, respectively. Percent depth dose diagrams for several photon square fields are shown in Figure 3 and 4.

Figure 5 presents the energy dependence for the field of 10×10cm^2.

A comparison of percent depth dose for wedged and open beam for square field of 10×10cm^2 is presented in Figure 6. A significant effect of radiation hardening as a result of beam wedging is clearly visible for the photon energy of 6MV – the dose decrease with depth is slower for the wedged beam.

In Table 2 the results of the symmetry and homogeneity checks and penumbra values for photon beams are presented. Chosen profiles for the 6MV photon beam are shown in Figure 7.

Dependence of the output factor on the square field size is shown in Figure 8. The values were normalized to the square field of 10×10cm^2.

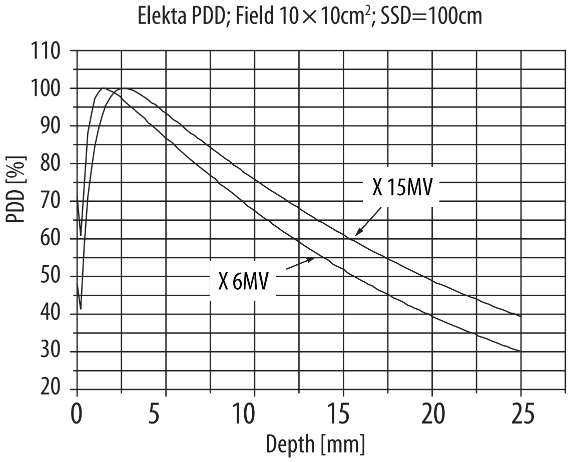

Figure 5. Percent depth dose curves in water for 6MV and 15MV photon beams (Dependence of PDD on energy).

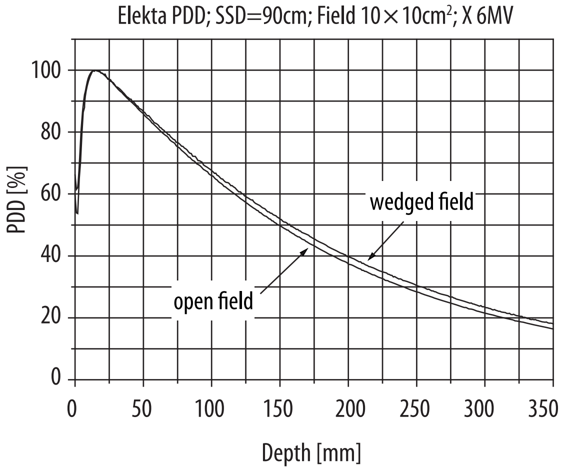

Figure 6. Percent depth dose curves in water for 6MV photon beam. A comparison of wedged and open beam for the square field of 10×10cm^2.

Table 2. Results of symmetry (S), homogeneity (H) and penumbra measurements for photon beams.

Field [cm^2]	X 6MV			X 15MV		
	S [%]	H [%]	Penumbra [mm]	S [%]	H [%]	Penumbra [mm]
10×10	100.98	104.94	6.8	101.14	105.03	8.0
20×20	100.96	104.40	7.2	100.46	102.77	7.8
40×40	100.92	105.70	8.5	100.66	104.17	9.2

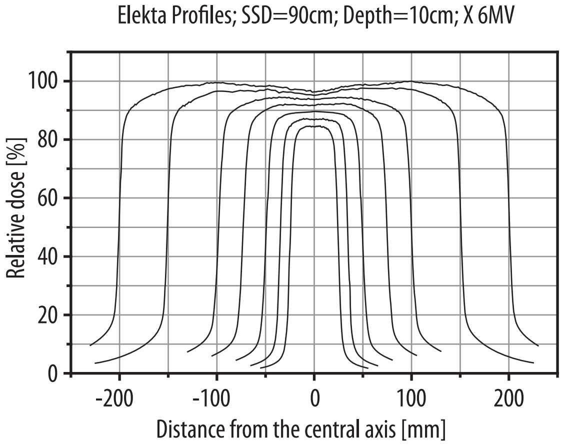

Figure 7. Beam profiles for 6MV x-ray for various square fields sizes between 5 and 40cm.

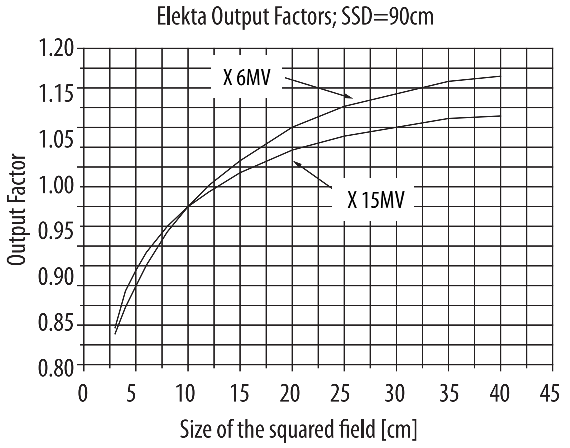

Figure 8. Relative dose factors (output factors) for two photon beam energies (6 and 15MV). Depth of 10cm.

Table 3. Characteristics of generated electron beams (Eo – initial energy, dmax – depth of maximum dose, Rp d – practical range from the percent depth dose curve, R50 d – the depth at which the absorbed dose is 50% of the dose at the absorbed-dose maximum, R 90 d – the distal depth at which the absorbed dose is 90% of dose at the absorbed-dose maximum).

Applicator 10×10; SSD=100cm					
Nominal electron energy [MeV]	Eo [MeV]	Dmax [cm]	Rp d [cm]	R 50 d [cm]	R 90 d [cm]
6	6.0	1.3	3.1	2.5	1.8
9	8.5	2.0	4.5	3.6	2.8
12	11.3	2.6	5.9	4.8	3.7
15	14.3	2.7	7.3	6.0	4.5
18	16.8	2.9	8.7	7.2	5.4
22	20.8	1.9	10.9	8.9	6.2

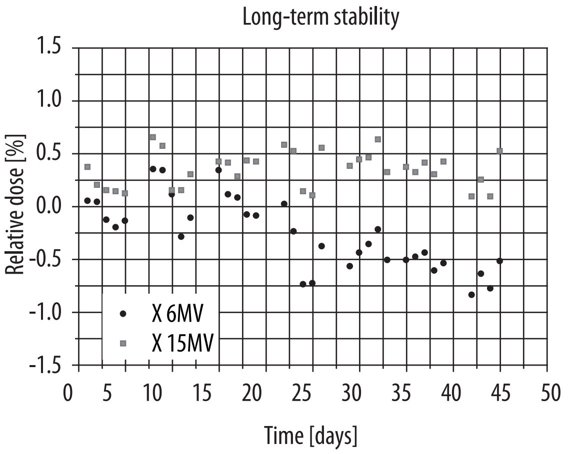

Figure 9. Results of stability measurements in the sequence of the day for X 6 and 15MV.

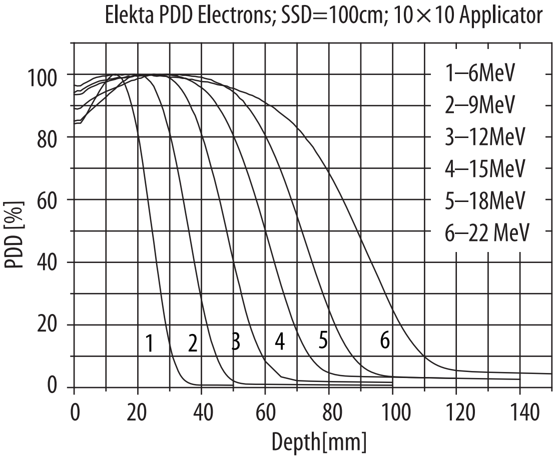

Figure 10. A comparison of percent depth dose curves in water for applicator 10×10 for various electron beam energies.

Results of the long-term stability for photon beams are shown in Figure 9.

The difference between the mean and expected value of output dose rate is connected with different time of calibration and daily routine measurement. Daily routine measurements were made in the morning, while calibration was usually performed in the afternoon hours, when the accelerator was well warmed up.

The value of stability throughout a day for both nominal energies was 0.2% with standard deviation of 0.2%. The reproducibility of dose rate measurements remained for both energies below 0.1%, proportionality below 0.3%. The maximum deviation in output stability vs. gantry angle was 0.6% at an estimated method error of 0.5%. This supports the conclusion that the output change at different gantry angles is insignificant.

Parameters of electron beams

Electron beam quality factors R50 ion [cm] determined for 25×25 applicator at nominal energies 6, 9, 12, 15, 18 and 22 took MeV were respectively: 2.44; 3.62; 4.82; 6.05; 7.20; 8.91 [cm].

Table 3 shows the set of chosen dosimetric parameters for electron beams.

A comparison of percent depth doses for applicator 10×10 for generated energies of electron beams is presented in Figure 10.

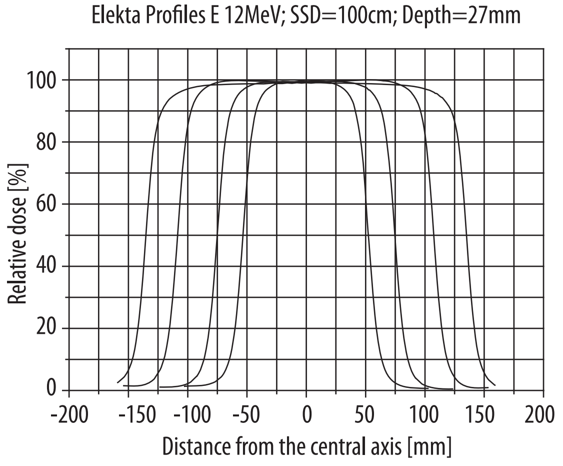

Figure 11. Beam profiles of 12MeV electron beams shaped with standard applicators for various square fields sizes between 10 and 25cm. The measurements were taken in water at the depth of maximum dose at the SSD of 100cm.

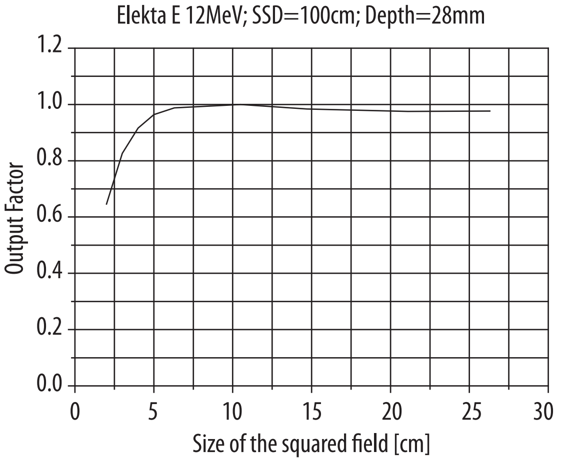

Figure 12. Relative dose factors (output factors) for electron beam energy of 12MeV.

Table 4. Results of symmetry (S), homogeneity (H) and penumbra measurements for electron beams.

Nominal electron energy [MeV]	Applicator 10×10			Applicator 25×25		
	S [%]	H [%]	Penumbra [mm]	S [%]	H [%]	Penumbra [mm]
6	100.68	103.80	11.5	101.17	103.42	11.1
9	100.41	105.02	12.6	100.49	103.39	13.0
12	100.48	104.66	12.3	100.65	104.22	12.9
15	100.49	103.26	10.8	100.42	104.48	11.1
18	100.70	102.72	9.4	100.60	102.14	9.3
22	100.56	101.69	5.7	100.71	102.33	5.6

Profiles of 12MeV electron beams shaped with chosen standard applicators; bundles formed for bundles with beloveds with standard applicators for the electronic radiation about energy are shown in Figure 11.

Figure 12 presents the dependence of the output factor on the square field size for electron energy of 12MeV. The calculated values were normalized to the square field of 10×10cm^2.

The output factor for a given electron field is additionally determined by the size of applicator chosen; it has been confirmed by more detailed studies. This effect results from the fact that the collimator jaws position (except for MLC) is fitted to the chosen type of applicator (these positions are different for different applicators).

The results of symmetry and homogeneity checks of electron beams as well as penumbra values are presented in Table 4.

Results of the long-term stability checks of electron beams at two chosen energies are shown in Figure 13.

The mean value of output stability throughout a day for electron beams was below 0.5% at standard deviation of 0.5%. The reproducibility value for all energies was less than 0.1%, whilst proportionality was less than 0.5%.

The maximum deviation in output stability vs. gantry angle was 0.8% at the estimated method error of 0.5%. This supports the conclusion that the output change at different gantry angles is insignificant.

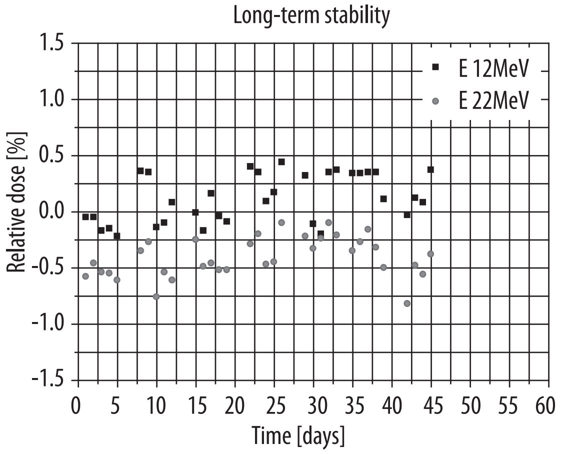

Figure 13. Results of stability measurements in the sequence of the day for 12 and 22MeV electron beams.

CONCLUSIONS

Acceptance tests performed according to manufacturer's and user's own procedures have shown the full compliance of the accelerator parameters with the ones declared in the specification and with the standard values given in the IEC standards [10–11] and the Polish national recommendations [7]. The survey of the machine's performance for over one year of its clinical work confirms good long-term stability of the parameters in question providing that the necessary environmental conditions are kept. The environmental parameters required are: relative humidity between 40 and 50%; room temperature kept within ±1 degree tolerance. Such conditions have an essential influence on reliable operation of the linac.

Routine measurements indicated the need for more frequent adjustment of the 6MV photon beam in comparison to other energies. This conclusion results mainly from national recommendations [7], which are more strict than IEC standards for fields greater than 30×30 cm. For such fields the national standard requires homogeneity tolerance of 106% and the actual linac parameter is very close to this value (see Table 2). However, such fields are seldom used in radical radiotherapy.

It is worth pointing out the symmetry and homogeneity values achieved for electron beams. Electron beam homogeneity equal to or less than 105% (at the tolerance of 110%) allow this accelerator to be ranked among world leaders. The operational parameters reported in initial acceptance tests have not worsened during the period of over one year. Elekta Precise® accelerator system is user-friendly. The possibility of constant monitoring of essential parameters for individual beams enables the user highly reliable quality assurance of patient therapy. An additional virtue, complementing the whole therapy line, is the Elekta's Record & Verify system, allowing for creation of any kind of check or therapy field on this accelerator.

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