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MECHANICAL AND ELECTRICAL INNOVATIONS IN THE DESIGN OF THE HORIZONTALLY MOUNTED SUB-MeV VAN de GRAAFF ACCELERATOR[1]

NIKOLA GODINOVIĆ, JOSIP TUDORIĆ-GHEMO, IVO JERČIĆ,
MATKO JOSIPOVIĆ, LJUBOMIR KULUŠIĆ

FESB, University of Split, R. Bošković b.b., 58 000 Split, Croatia

and

JAVOR ŠKARE

"Brodograđevna industrija Split", Put Supavla 21, 58 000 Split, Croatia

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The construction of the insulating column of the horizontally mounted Van de Graaff accelerator has been implemented using the new composite materials with the corresponding mechanical and electrical characteristics. Three supporting bolts fix the equipotential plates and the system exhibits vanishing vibrations and a negligible decline. The low frequency stabilization of high direct voltage has been implemented controlling the spray voltage by the thyristor transducer. The signal proportional to high voltage fluctuations changes the thyristor triggering delay angle in the primary circuit of the spray generator. The mathematical model predictions of the high voltage stability are confirmed by the corresponding measure-

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ments. The achieved stability permits the proton implantation experiments and it is a reliable basis for designing high frequency stabilization even at very low energies.

1. Introduction

The 600 keV Van de Graaff accelerator at the University of Split is horizontally mounted. The insulating column, the set of aluminum plates at equidistant intervals by inserting the disk-like glass insulators ($\phi = 50$ mm, $d = 20$ mm), was originally glued by a two-component epoxy resin [1]. A new mechanical construction of the insulating column was required because in operation the accelerator behaved like a forced oscillator and the unbalanced strains caused the breaking of the thin glue films resulting in the crushing of the glass insulators. The essential problem was to select a type of new composite materials with adequate mechanical and electrical characteristics. After the successful implementation of the new insulating column construction we were able to consider the problem of accelerator high voltage stabilization. While measuring the accelerator high voltage we observed a pronounced drift effect independent of the value of the selected starting voltage. In these conditions it was impossible to bring in a beam through the magnetic analyzer. We had to implement the low frequency high voltage stabilization. The regulating system based on the thyristor transducer was chosen to control the spray voltage.

2. The new construction of the insulating column

Fig. 1. shows the new fastening of the insulating column carried out by means of three bolts fastened to the ground supporting slab of the accelerator. The composite material, trademark VMT SIPAS 60 [2] (basic component-polyamid) was chosen for the bolts.

The aluminum plates and the rings (made of the same material as the bolts), which provide the 20 mm equidistance of the plates, are disposed in layers on the bolts structure. The other ends of the bolts have nuts for tightening. We found out that the disk with $\phi = 30$ mm and $d = 20$ mm provides the required electric resistance 100 GΩ which is 50 times greater than the corresponding resistance value between two adjoining column plates of the accelerator voltage divider. Additional tests of the electric resistance showed that its value did not change considerably in the temperature range from 293 K to 423 K.

The bolts diameter (inner rings diameter) $\phi = 18$ mm was determined on the basis of mechanical stress analysis and the known outer diameter of the rings. The material used withstands the allowable stress of 50 MPa which ensures a high factor of safety since the maximum stress in the upper bolts is 6.7 MPa. By approximating the accelerator construction as a mechanical system with one degree of freedom and by determining the equivalent stiffness, we estimated the first natural frequency of the mechanical system to be 15 Hz. As the driving motor of the charge-carrying system has mechanical frequency of rotation 46.6 Hz, it is not possible to expect any

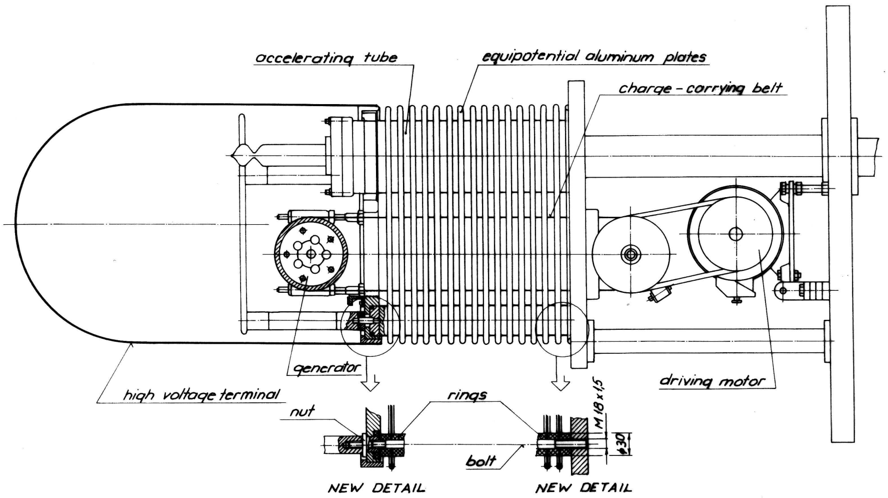

Fig. 1. Van de Graaff accelerator.

considerable vibrations. The selected material damps vibrations better than glass so that they are practically eliminated. Another advantage of the new construction is a much simpler accelerator servicing (charge-carrying belt exchange).

3. The low frequency control

The low frequency stabilization system is based on negative feedback control [3]. Fig. 2. shows a schematic diagram of the stabilization system. A built-in generating voltmeter is used as a measuring element. To improve the signal to noise ratio of the generating voltmeter the original "measuring head" (four quadrants and two-leafed rotating electrode) is replaced by a new one of eight octants and a four-leafed rotating electrode [4]. The feedback signal processing circuit converts the generating voltmeter ac signal to the dc voltage signal which is proportional to the terminal

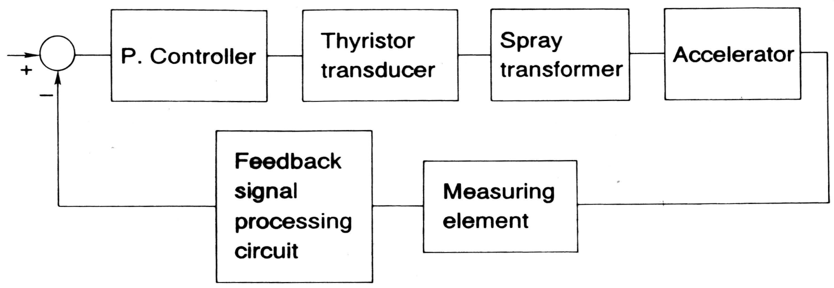

Fig. 2. Schematic diagram of the stabilization system.

high voltage. This dc signal is compared with the reference signal. On the basis of the difference between these two signals the P-controller yields the error signal for actuating the correction. The central signal is the error signal superimposed on the direct voltage signal, the value of which can be selected. This allows the choice of the most favourable operating point of the thyristor transducer. The two thyristors antiparalelly coupled are the basis of the thyristor transducer which controls the primary current of the spray transformer: the higher control voltage resulting from the rises of the terminal high voltage causes a delayed turn-on of the thyristor so that the spray current is reduced. A change of thyristor triggering delay angle is implemented by trigger devices using integrated circuit TCA-785-SIEMENS [5].

4. The control system analysis and results

The stability analysis was carried out before implementing the regulating system. The control loop transfer function is the basis for mathematical analysis of the stability. The particular elements of the regulating system are represented by the corresponding transfer functions [6]. Fig. 3. shows the block diagram of the con-

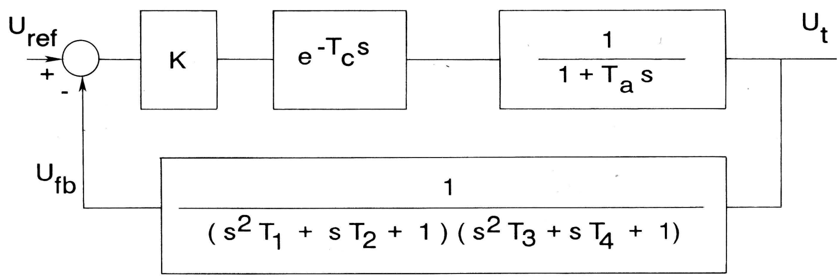

Fig. 3. Block diagram of the control loop.
K – open loop gain; T_c – complete time delay including the time delay of charge-carrying belt, thyristor transducer and generating voltmeter; T_a – accelerator time constant; T_{1-4} – time constants of the electronic processing circuit of the feedback signal.

trol loop. The open loop transfer function and the corresponding characteristic equation can be deduced from the block diagram. The analysis shows that all the roots of the characteristic equation have negative real parts, which means that the stability criterion is fulfilled. The Nyquist diagram shown in Fig. 4. also confirms that the system is stable. From Nyquist diagram it can be seen that the gain margin exceeds 2 (6 dB), which is the acceptable safe degree of stability [7]. The corresponding measurements given in Table 1. confirm the reliability of the implemented regulating system. The selected high voltage values were fluctuating within the quoted intervals. The most prominent fluctuation frequency is the ripple

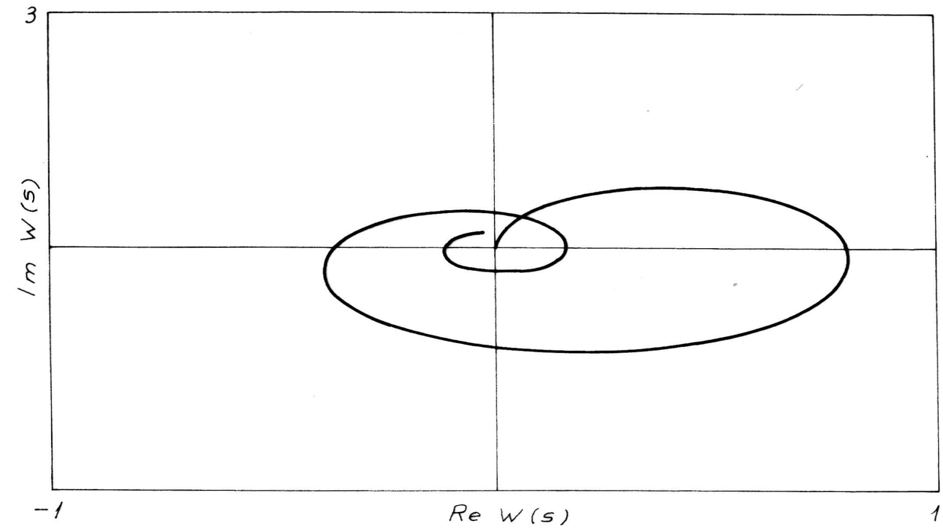

Fig. 4. Nyquist diagram of the stabilization system.

Table 1. Results of measurements of the reliability of the implemented regulating system.

Measured values*

U_T(kV)	I_{pc}(mA)	I_{sc}(μA)	I_b(μA)
31 ± 3	18 ± 0.9	15 ± 0.8	5.5 ± 0.2
58 ± 3	21 ± 1	20 ± 1	4.5 ± 0.23
110 ± 3	27 ± 1.4	33 ± 1.7	7.0 ± 0.35

U_T–terminal high voltage
I_{pc}–primary current of spray transformer
I_{sc}–secondary current of spray transformer
I_b–proton beam current
*–without closing the pressure vessel

frequency of the rectified spray voltage. When the pressure vessel was closed, these fluctuations were attenuated and their values were about 1% of the selected high voltage. The implemented low frequency stabilization provides a reliable basis for bringing in a beam through the magnetic analyzer and has already made possible proton implantations [8].

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MEHANIČKE I ELEKTRIČNE INOVACIJE KOD HORIZONTALNE IZVEDBE SUBMEVSKOG VAN de GRAAFF AKCELERATORA

NIKOLA GODINOVIĆ, JOSIP TUDORIĆ-GHEMO, IVO JERČIĆ, MATKO JOSIPOVIĆ, LJUBOMIR KULUŠIĆ

FESB, University of Split, R. Bošković b.b., 58 000 Split

i

JAVOR ŠKARE

"Brodograđevna industrija Split", Put Supavla 21, 58 000 Split

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Konstrukcija izolacijskog stupa Van de Graaff akceleratora horizontalne izvedbe ostvarena je koristeći novi kompozitni materijal s odgovarajućim mehaničkim i električnim karakteristikama. Tri noseća svornjaka od izabranog kompozitnog materijala fiksiraju ekvipotencijalne ploče. Vibracije konstruiranog izolacijskog stupa su iščezavajuće, a progib stupa je zanemariv. Spora stabilizacija visokoga istosmjernog napona je ostvarena tiristorskim pretvaračem koji upravlja naponom posipanja. Signal razmjeran fluktuacijama visokog napona mijenja kut vođenja tiristora u primaru transformatora za posipanje. Matematičkim modelom utvrđena je stabilnost projektiranoga stabilizacijskog sustava. Stabilnost izvedenog sustava je potvrđena odgovarajućim mjerenjima. Postignuta stabilnost omogućuje eksperimente s implantacijom protona i pouzdana je osnova za izvedbu brze stabilizacije čak i pri veoma niskim energijama.