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VIVITRON

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A BELT CHARGING SYSTEM FOR THE VIVITRON - DESIGN, EARLY RESULTS ?

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OCTOBRE 1990

CENTRE DE RECHERCHES NUCLEAIRES

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This report is based on an invited paper presented
at the Symposium of North Eastern Accelerator Personnel
held in Manhattan (Kansas University)
22 - 26 octobre 1990

The proceedings of this meeting will be published
by "World Scientific".

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ABSTRACT

A specific belt charging system has been designed, built and assembled for the 35 MV Vivitron. 100 m long belt is used. Together with main features of the design, experimental studies, tests in a pilot machine and the results of the very early tests of the real system are reviewed.

1. Introduction

The 35 MV electrostatic high voltage generator, part of the future Vivitron accelerator [1], is being completed these days. It is fed by a belt charging system that could so appear as a very (old) conventional design. However that is not the case, apart from the basic principle of running a belt on which charges are trapped. Due to the general design of the Vivitron, to its high voltage and the resulting electrical, mechanical and geometrical constraints, and according to the specific ideas developed in the laboratory these years about belt running in electrostatic accelerators, the present charging system for the Vivitron [2] is strongly different from the previous ones, both mechanically and electrically.

Its whole assembly had been achieved last year and preliminary, short circuited, air atmospheric pressure tests have been done right at the end of 1989. Further electrical tests require SF_6 pressure so they have been delayed up to the next days ... Early results could perhaps be given by the time of this meeting.

2. Conceptual design

Sketch of the present charging system for the Vivitron is shown in Fig. 1. Due to its length and the number of rollers, it can appear more like an industrial (mining ?) conveyor than as an electrostatic charging system.

The 50 m long column, radially supported by the posts, is

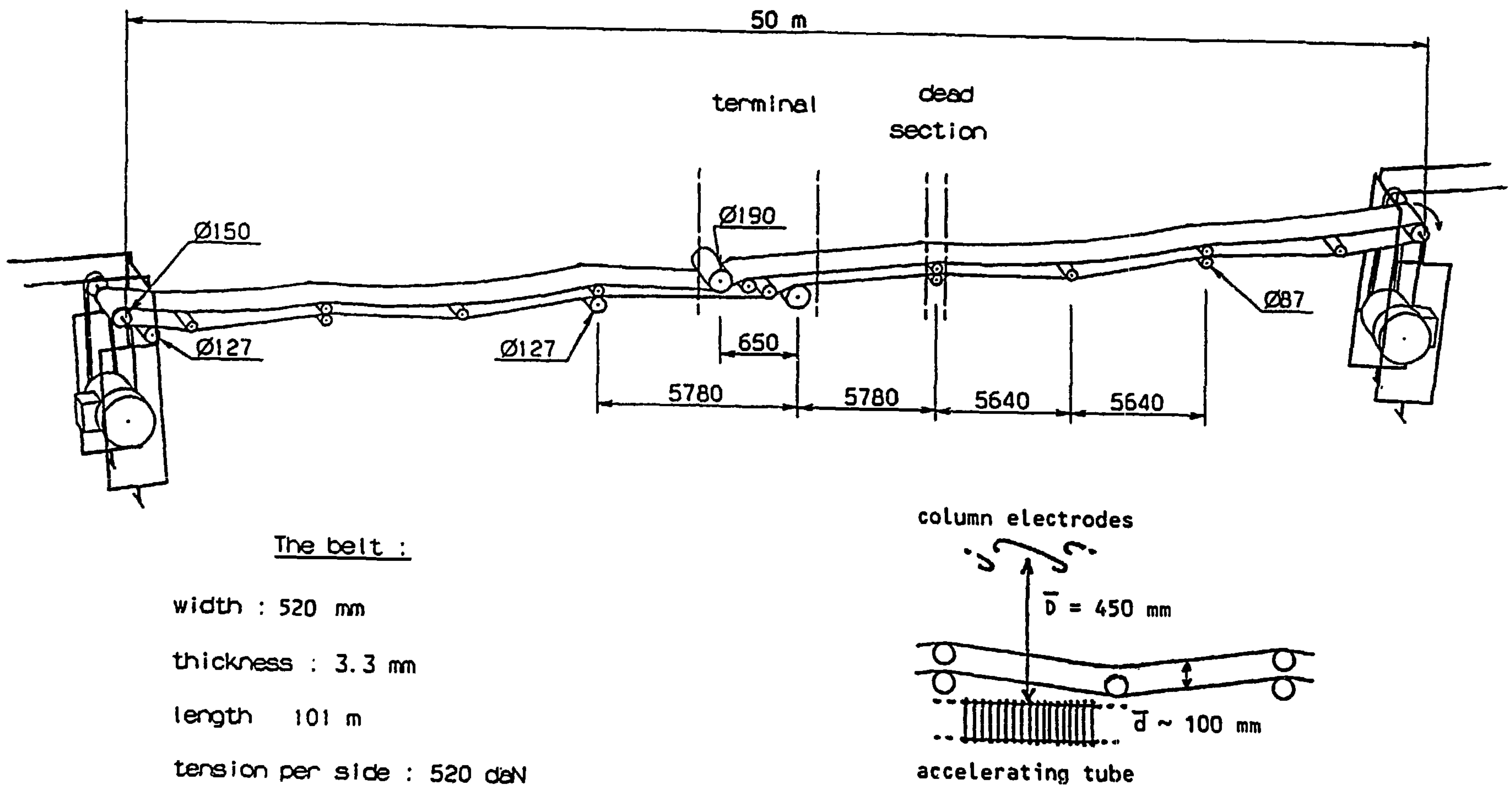


Fig. 1 Sketch of the present charging system for the Vivitron

longitudinally weak and could not bear the belt tension as it usually does in accelerators. The use of a 100 m long belt through the full length of the vessel solves this problem while giving the possibility to extend the tandem symmetry to a double up and down charge arrangement as shown on Fig. 2, so lowering charge densities and related fields for a given total intensity by a factor of 2.

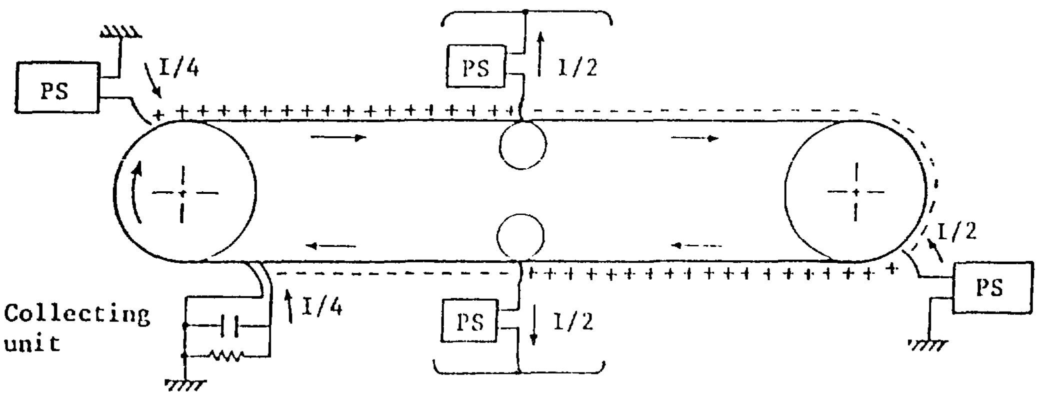


Fig. 2 Symmetrical belt arrangement with four oppositely charged portions, each one running from the ground to the terminal, then back to ground. The commutation system is illustrated for a total current I.

The distance "d" of the two facing portions of the belt is kept rather small (at least in active sections with longitudinal field) compared with the overall distance "D" between the surrounding conducting pieces (column electrodes and tube) (Fig. 1 and 3) according to the principle of the so-called decoupled structure [3, 4] Fig. 4. In such an arrangement, when facing charge densities are opposite ($+\sigma$; $-\sigma$), the transverse field is almost confined between the two symmetric up and down charged portions where it is about uniform whatever the geometry of the surrounding conductive pieces which induces non-uniformity only for the weak field outside the two belt portions.

In order to ensure the required symmetry of the facing charge densities the commutation arrangement (shown on Fig. 2) uses four active current regulated charging ionisers plus only one "collection" ioniser giving the "zero" charge reference.

Thanks to the previous features the belt speed could have been lowered to 10 m/s still keeping electrical constraints low enough (σ ~2,6 nC/cm^2, $E_t \leq 24$ KV/cm uniform) for the required 500 µA total intensity.

This low speed also enables us to keep the total power requirement for the charging system at the same level than this of the MP, that is to say ~33 KW including the electrical work P_e = 35 MV x 500 µA = 17,5 KW. the gas friction P_f ~3,5 KW (> 14 KW fot the MP), the provisional power in the terminal P_u = 8 KW and mechanical losses (bearings, belt ...). Should the speed be the same as for the MP gas friction losses would have been ~50 KW and the total power > 80 KW !

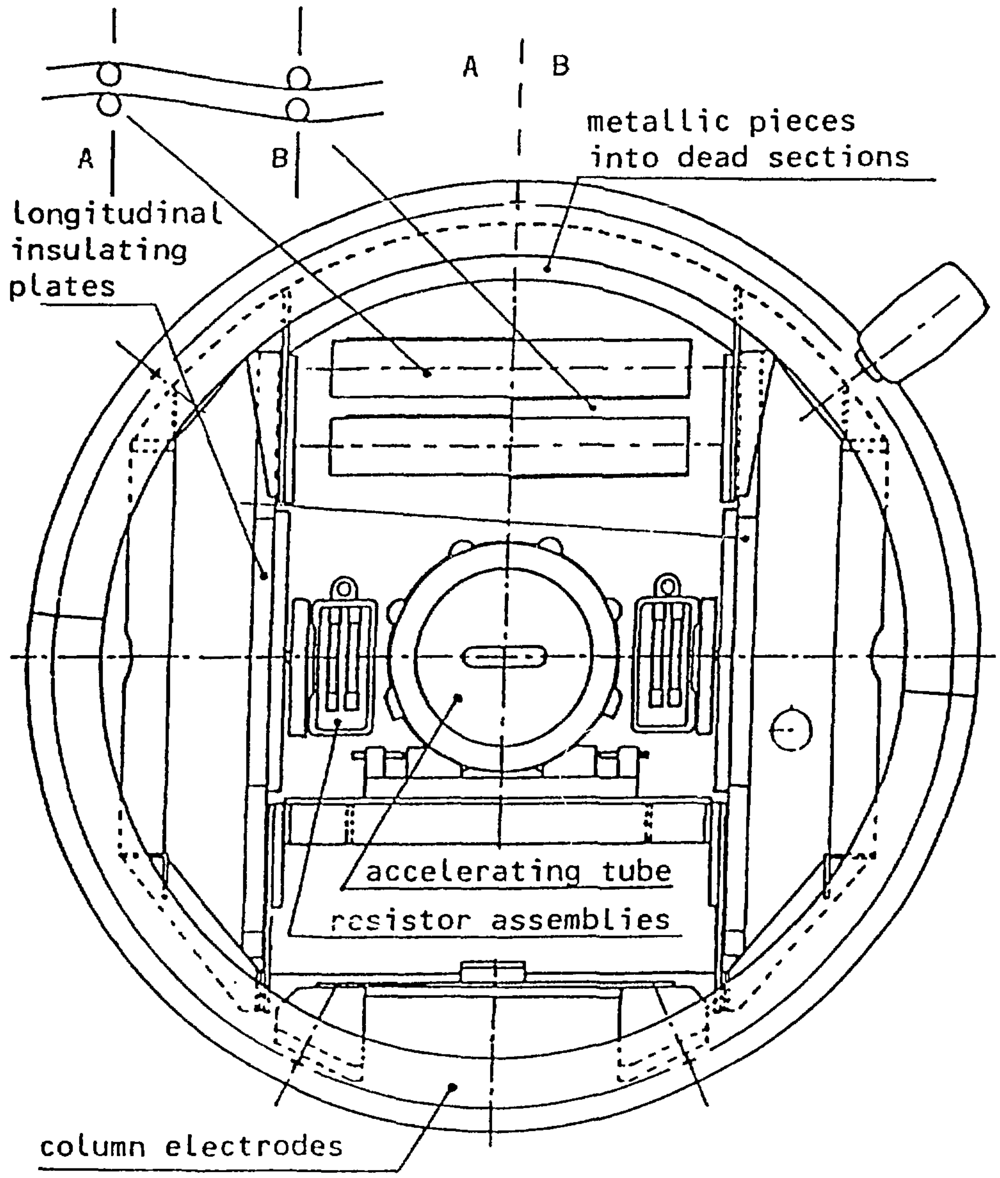


Fig. 3 Column cross-section and belt location in two successive dead sections : A (left), B (right).

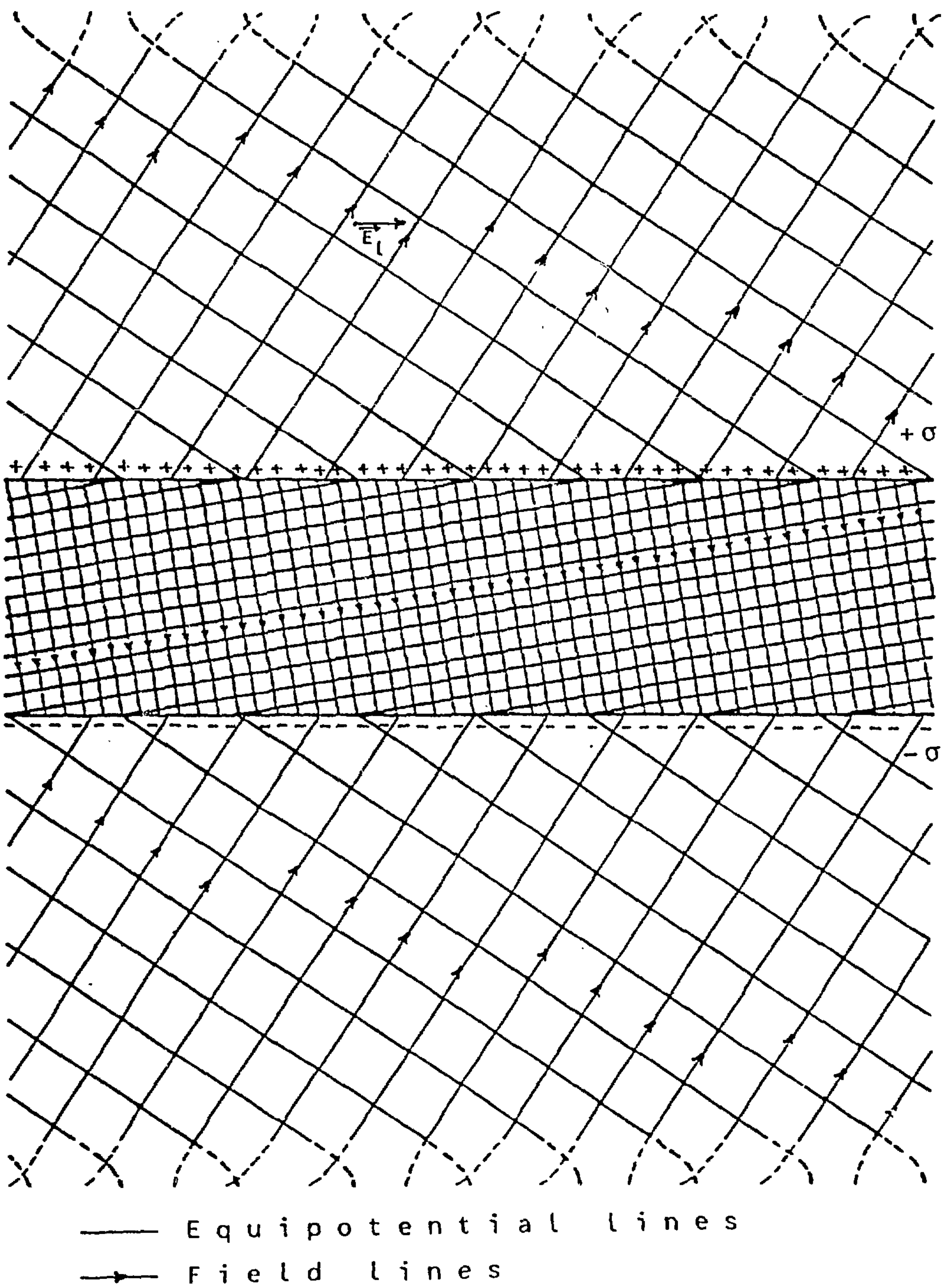


Fig. 4 Potential and field lines for a typical decoupled structure with equal up and down charge densities

In addition to that, the parasitic charge generation will also be reduced accordingly, which is a definite advantage for such a large charging system where the number of rollers, although minimized, is still 19, including driving pulleys and generators (Fig. 1).

However the high power required and the low speed chosen lead us to design a double drive conveyor sharing the load between two pulleys as to avoid extreme values of mechanical stress that the belt could not withstand.

The supporting rollers had to be located in the dead sections along the column. Their arrangement and their diameters have been determined in trying to get a good trajectory of the belt at maximum charge density while keeping it acceptable with no electrical charge, using a minimum number of rollers, and limiting the counter flexions (see § 3.2).

Considering early a belt charging system it appeared at that time that a 100 m long H.V.E.C. endless conventional belt would be very expensive and even could not be manufactured. On the other hand good results had been reported [5] with a different belt (the "Swedish" one) which, being spliced, was available in such a length.

3. Experimental studies

In order to collect necessary information both about the Swedish belt characteristics, and the running conditions of the 50 m long conveyor (5 x that of the MP, 10 x the longest Swedish belt ever used in an accelerator) at 10 m/s high speed (~10 x the usual speed for long belt conveyors in industry) and high power (> 30 KW), an experimental program has been raised.

3.1. Mechanical test bench

A one-to-one test bench but only ~half length (27 m) with no SF6, no pressure, no voltage and limited power (~8 KW) has been designed, assembled and run with a 54 m Swedish belt. Various parameters have been studies e.g.

- Elastic and permanent lengthening of the belt,
- Required mechanical stress,
- Sliding coefficients against rollers,
- Sags and related forces versus supporting arrangement,
- Torques and related power,
- Static and dynamic tracking (mean trajectory and its stability),
- Double drive,
- Electrical power generation from the belt ...

The results have mostly confirmed the previous theoretical design. They also have shown numerous mechanical and geometrical defects of the test belt which have now been partly corrected by the manufacturer for the present belts (including this one for the Vivitron).

3.2. 7 MV Pilot machine tests

In 1986 a Swedish belt was simply put in the 7 MV CN accelerator with no special attention compared with an H.V.E.C. one. It has been running for long, but with low currents, mainly for testing the posts for the Vivitron.

However it had been foreseen since long that it was necessary to thoroughly investigate the behaviour of the Swedish belt under realistic conditions close to those planned for the Vivitron. In 1989 when the tests of the posts were achieved modifications were done to the CN such as to test model charging systems of the Vivitron.

A model about similar to the initial design [6] of the Vivitron where Ø 112 mm guiding rollers associated with Ø 315 mm MP type driving pulleys imposed severe 30° counter flexions to the belt ,has been first tested but with a speed of 15.6 m/s while the rest mechanical tension was limited to 380 Kg-f for 520 Kg-f for the Vivitron.

While scaled 6.5 MV (for 35 MV) voltage, and 200 μA per side (for 125 μA) current, nominal performances have been easily demonstrated both with the conventional CN arrangement as well as with the model charging system, two serious problems have been encountered with the last.

The first, we already knew about, is the high parasitic charge generation from rollers on the (outside) rubber face. With a brand new belt currents as high as hundreds of μA flew, that are able - and they did once - to destroyed at once the belt by surface flashover while you are just running it for the first time. Those currents decrease then in hours down to a non dangerous level (tens of μA) still undesirably high for running the Vivitron.

The other problem is the extreme limitation of the belt lifetime due to the tear of the glued splice) compared with several thousands of hours reported and experienced by ourselves with that type of belt in the same conditions but with the conventional CN arrangement i.e. without guiding rollers at the outside.

None of these problems had been experienced before apart the first one in Aramis 2 MV tandem in Orsay where such a belt is running with the rubber face inside. It came obvious that they are both caused by the counter flexion winding of the spliced belt over small diameter rollers and that they are related with winding angle, belt speed, belt tension ...

To solve these difficulties there is an alternative, either to use an endless, or at least better spliced, belt which would have inherent low parasitic charge ability, or to modify the mechanical arrangement according to the above analysis.

Although we have previously got a formal negative answer from H.V.E.C. about manufacturing a 100 m long belt at a time where we were not strongly motivated as we relied on the use of the much cheaper

Swedish belt, we asked again to V.H.V. which finally proposed us a way of making a long belt from a carcass the same type, but with an interwoven splice, and with the same coating process. As it will hopefully be tough enough but because it would also be at least as expensive as a conventional H.V.E.C. belt so long, we have first ordered a short one for testing it in the pilot machine and just received it days ago.

The second solution has been also investigated resulting in the final arrangement with only one over four guiding rollers kept with an increased Ø 127 mm and a decreased angle from 30° to 6° thanks to only Ø 150 mm driving pulleys (Fig. 1 and 5). Tests of a model arrangement very close to this one, with nominal speed and rest tension - but with low power - have resulted in very encouraging serious improvements both for the lifetime and the parasitic charge level such as we could think about thousands of hours and μA range per roller for the Vivitron.

Furthermore measurements are being done with the charging power supplies of the Vivitron (standard Glassman 15 KV, 15 W) investigating the behaviour of ionisers, particularly 50 μm thick steel sheets versus conventional Ø ~5 mil, 80 mesh stainless steel screens. First results show that the main difference is that the screens modify at the very beginning the surface of the belt making it slightly scratched but essentially more shiny ,while the sheets leave it almost unmodified, still about mat, after hundreds of hours. For the electrical point of vue it also seems that the resulting surface condition is the important parameter in the commutation process. As a whole, sheets and screens seem to be simply equivalent in a charging position for mean currents (typically 150 μA) while screens need less voltage for lower currents but more for higher. However, differences in voltage stay of the order of 20 % when absolute voltage for a given current varies with time by about 100 %. On the other hand in a collecting position, the efficiency of the sheet - defined as current collected from a given charge density - appears to be 30 % or so less than this one of a screen. There is few dust for both but even less for sheets.

4. First tests of the real Vivitron charging system

The Vivitron charging system was first built according to the initial design, completely assembled in november last year and mechanically tested by the end of 1989.

Modifications above mentioned were undertaken early this year and the final arrangement was fully assembled and mechanically adjusted by the end of may under atmospheric air with neither voltage (all the conducting pieces around being grounded), nor supplied charges.

Both arrangements are mechanically satisfactory. Thanks to the careful alignement of every roller or pulley, mean trajectory was very easily adjusted and almost perfect with the first as it had been demonstrated on the test bench. With the second one, adjustment suffers from the lack of

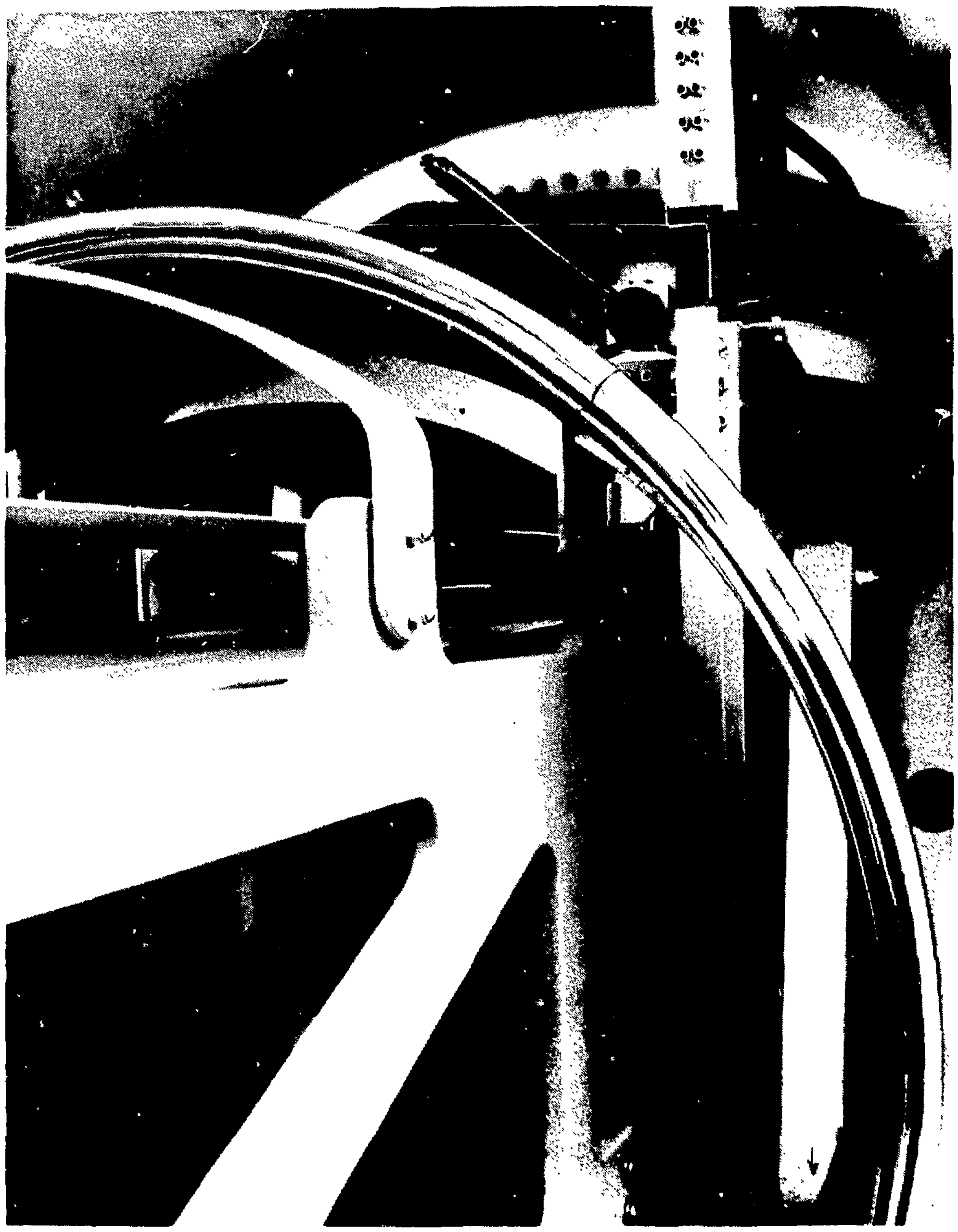


Fig. 5 View of the HE end station of the modified charging system showing the belt on the driving pulley and the left guide roller.

guiding roller at LE end such as the mean trajectory is perhaps no so perfect, but still quite good ,as only 5 mm apart from the 50 m long axis. Tracking is in contrast quite large with both arrangements. With the brand new belt in the initial arrangement it was first 24 mm and had been reduced to 14 mm by cutting both sides of the belt while running at full speed. It became worse again (21 mm at the HE end where the guiding roller is ,and 25 mm at the BE end) with the modified geometry. However we decided not to try to improve it again, since the belt is already only 485 mm wide.

As in the pilot machine very high currents of several hundreds of µA have been measured on rollers with the brand new belt. Residual level after some hours was ~200 µA and down to ~80 µA during short test with the final one guiding roller arrangement. Surely it will go down to few µA after few hours in dry SF_6.

Induced vibrations level were evenly low.

5. Conclusion

The charging system of the Vivitron, although using a belt, presents numerous special features, some because of particular constraints, the other coming from new ideas raised in Strasbourg. Its design has been widely confirmed by an intense experimental program. The mechanical behaviour of the final sbeltystem is quite satisfactory. Observed defects (mainly tracking, possible limited lifetime and parasitic charge level) are due to the use of a long Swedish belt with outside rollers, particularly guiding rollers with high counter flexions, although such a belt is able to run very well in more usual conditions).

Electrical behaviour has been qualitatively demonstrated in the 7 MV pilot machine but with only one roller and with low power. It has not been tested yet in the real system but it will be hopefully very soon.

6. References

1 M.Letournel and the Vivitron Group, "Present status of the Construction of the Strasbourg 35 MV Vivitron Tandem" Nucl. Inst. and Meth. A268 (1988) 295

2 J.M.Helleboid et al, "First Results with the Charging System of the Vivitron" presented to 1990 EPAC Conférence, Nice (France) 12-16 june, to be published.

3 M.Letournel, "Belt Charging System, Characteristics, Problems, Structures", presented at the SNEAP Conference, Los Alamos, New Mexico, Sept 1977

4 J.M.Helleboid, "Belt Charging System for the 35 MV Vivitron Accelerator", Nucl. Instr. and Meth. A268 (1988) 414
5 B.Hemryd, Uppsala University Annual Report (1984)
6 J.M.Helleboid, "A Charging System for the Vivitron", Nucl. Instr. and Meth. A287 (1990) 99.

A BELT CHARGING SYSTEM FOR

THE VIVITRON

DESIGN, EARLY RESULTS ?

J.M. HELLEBOID

OCTOBER 1990

LONG ESTABLISHED PRINCIPLE

+

LAB'S LARGE EXPERIENCE

+

NEW IDEAS AND DEVELOPPEMENT WORK

versus

VARIOUS PARTICULAR CONSTRAINTS

LENGTH OF THE COLUMN

POWER REQUIREMENT

RESTRICTED SPACE AVAILABLE

THE FEWEST POSSIBLE CONDUCTING PIECES

. . .

⇓

BELT CHARGING SYSTEM FOR THE VIVITRON

I) Main features of the conceptual design.

II) Experimental studies.

- II-1 Mechanical test bench.
- II-2 7 MV modified CN pilot machine.

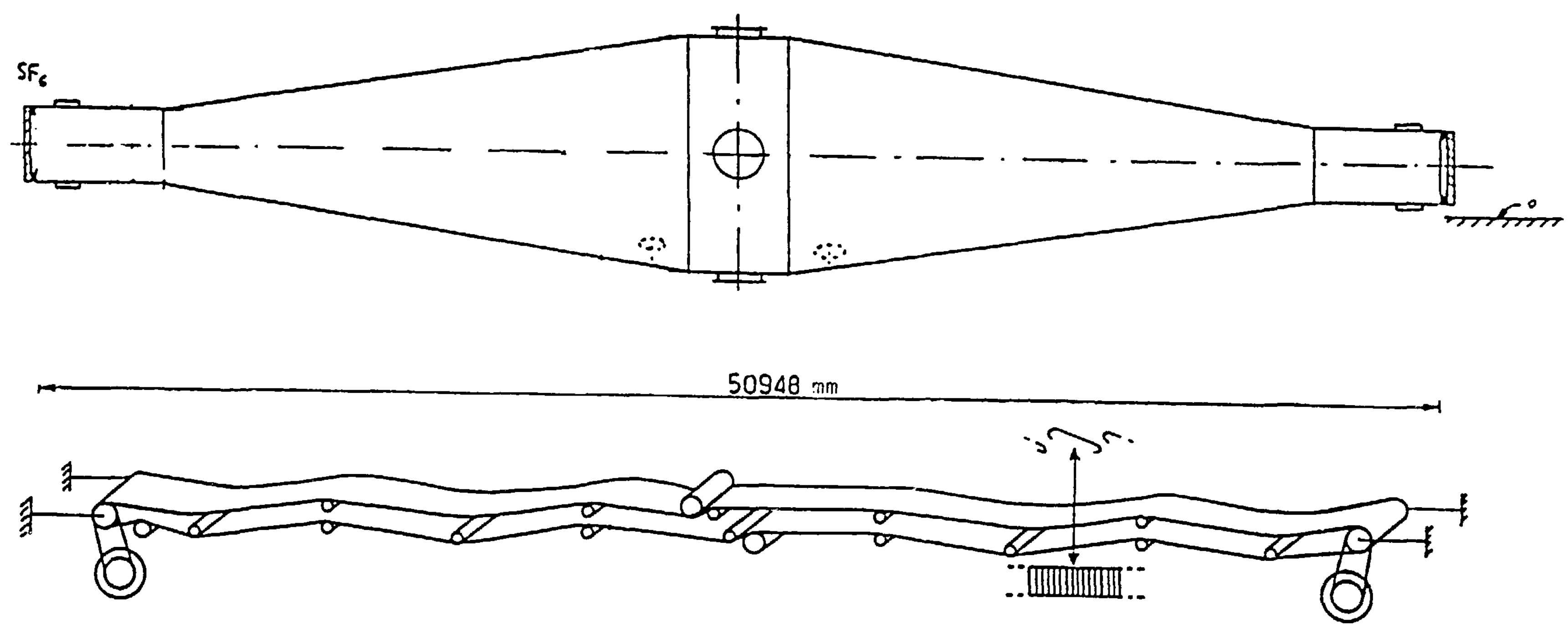
III) Main characteristics.

- III-1 The belt.
- III-2 The conveyor.

IV) First tests.

V) Sheets versus screens as ionisers.

FULL BELT LENGTH EXTENDING THROUGH THE TOTAL LENGTH OF THE MACHINE

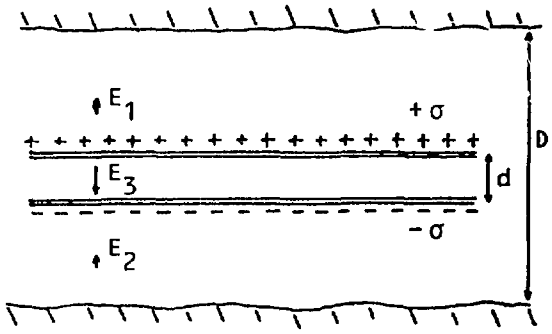


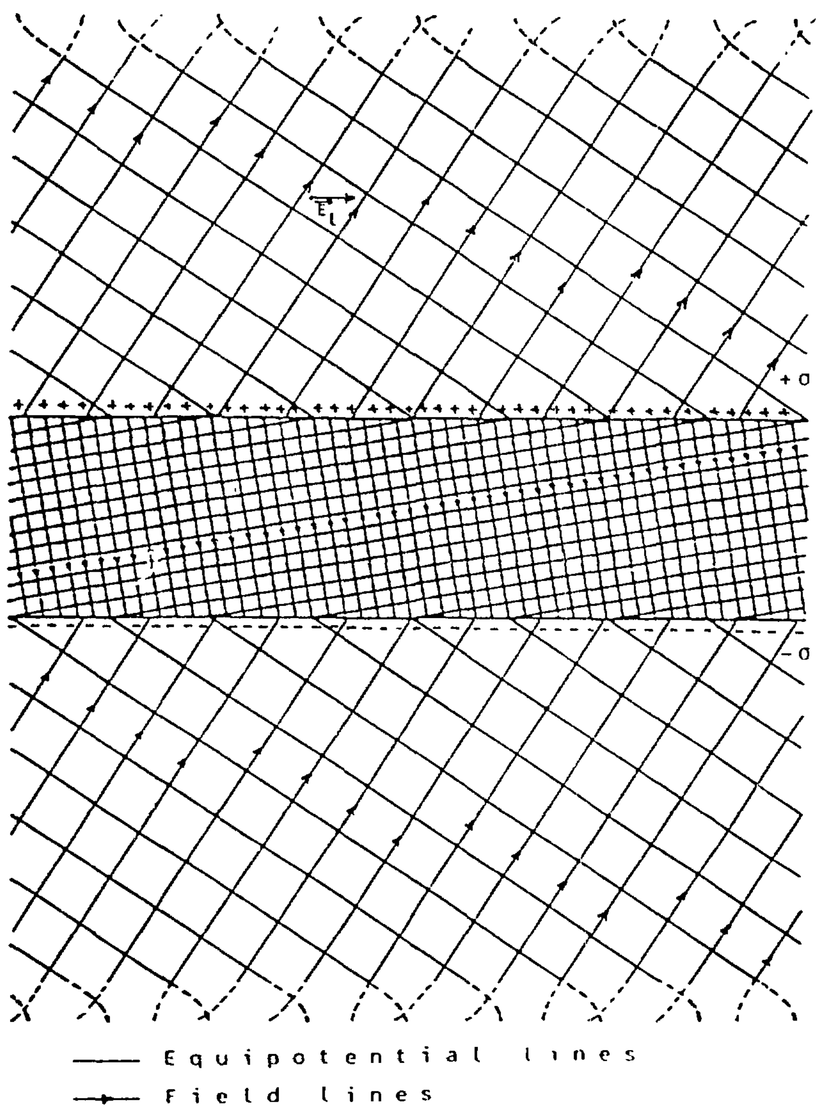
- No longitudinal mechanical stress on the column
- Double up and down charge (four active [+ or - σ] portions of the belt)

DECOUPLED BELT STRUCTURE

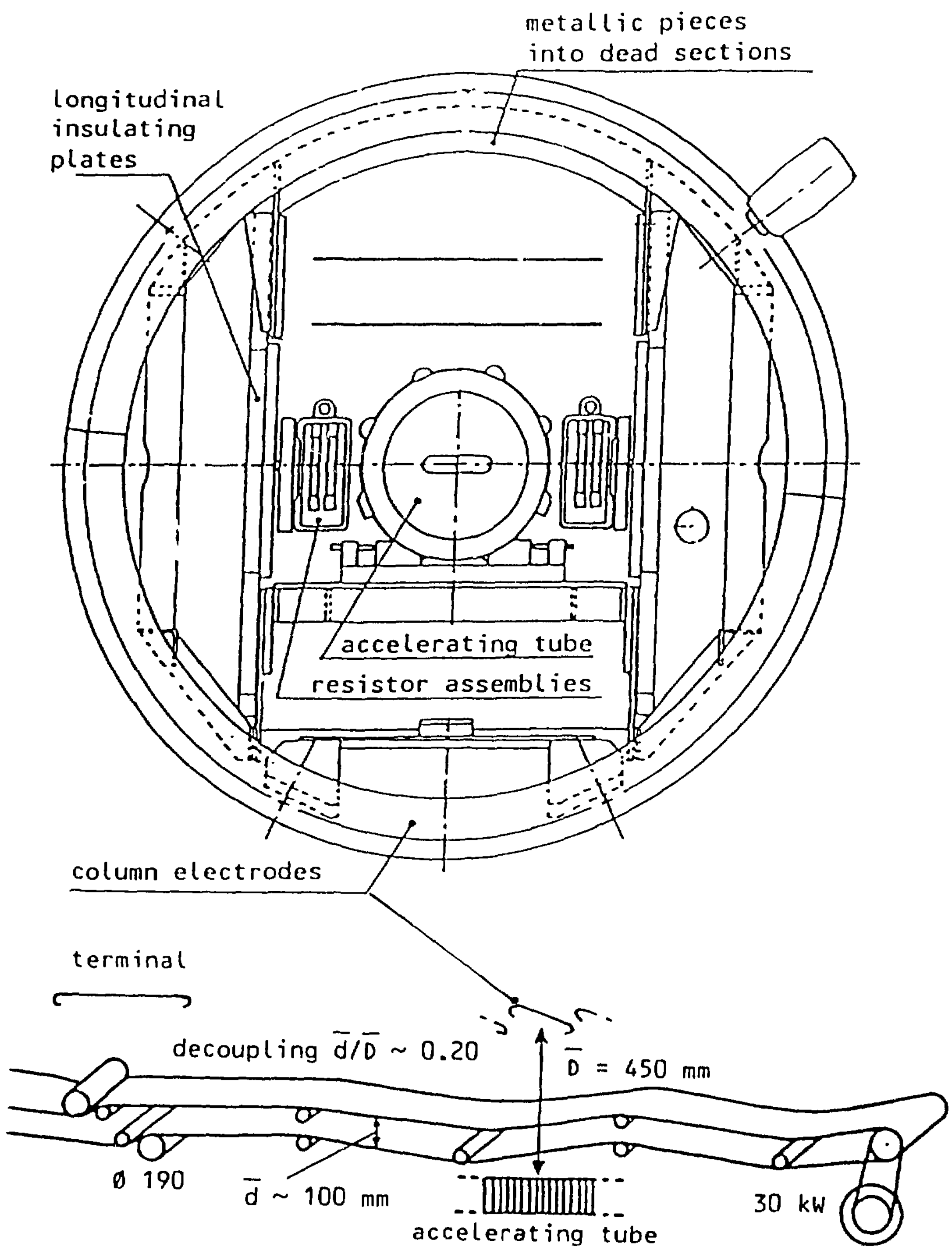
$$E_1 = E_2 = \frac{\sigma}{\varepsilon_0}\frac{d}{D}$$

$$E_3 = -\frac{\sigma}{\varepsilon_0}\frac{D-d}{D}$$

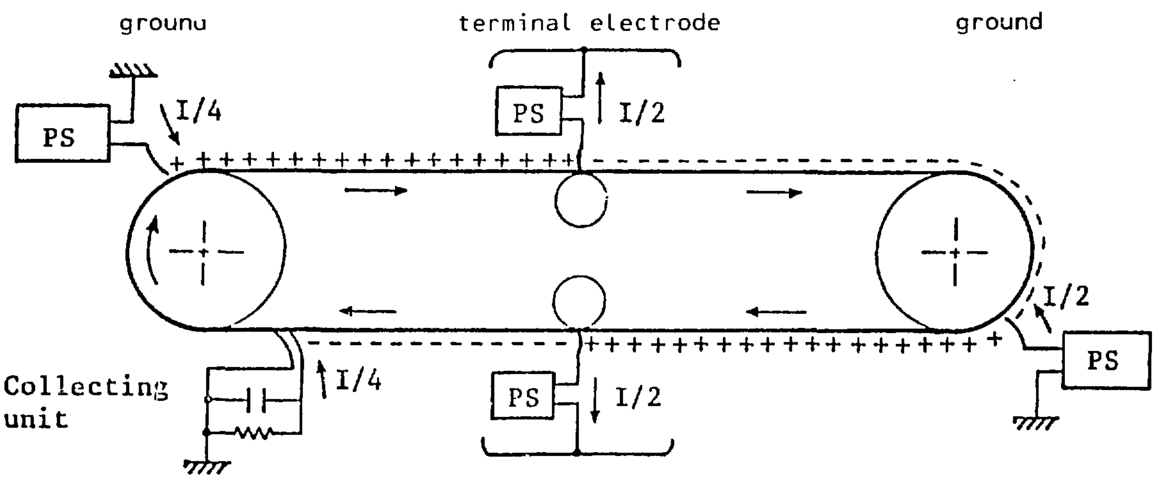




DECOUPLED BELT STRUCTURE



WELL CONTROLLED CHARGE COMMUTATION AND EQUILIBRIUM



- Three out of four commutations (+ σ → – σ or vice versa) each done by only one current regulated charging ioniser
- The last one done by a double collecting ioniser (→ O ± Δσ) followed by a fourth current regulated charging ioniser

REDUCED BELT SPEED

DOUBLE UP AND DOWN CHARGE
reducing the charge density for a given current

and the DECOUPLED STRUCTURE ARRANGEMENT
enhancing the electrical holding for a given charge density

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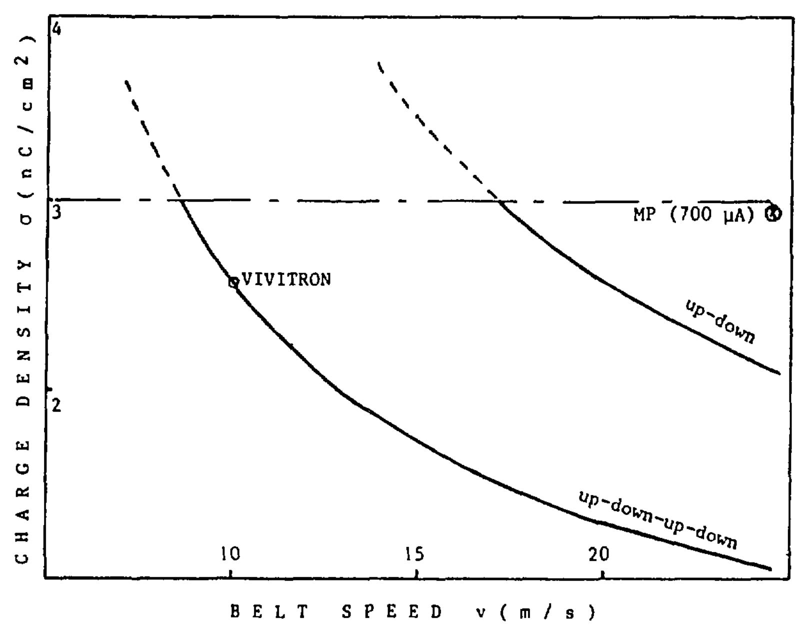
ALLOW FOR 10 M/S BELT SPEED
for the 500 μA needed

- Still reducing the electrical stress for the same 2.6 nc/cm² charging density than for the MP



- Also limiting the gas friction power losses to 3.5 KW
  50 KW for the Vivitron with MP speed
  14 KW for the MP

- Accordingly reducing the friction charge generation

BELT MATERIAL

- 100 m long usual endless H.V.E.C. belt

- New, spliced belt from Sweden already experimented as a charging belt 100 long available

BELT SUPPORTS

- Rollers with new designed ball bearings only 2200 r.p.m.

DOUBLE DRIVE

- Needed for the 33 KW power required at only 10 m/s speed to avoid minimum stress of ~ 750 Kg-f per side that the belt could not withstand

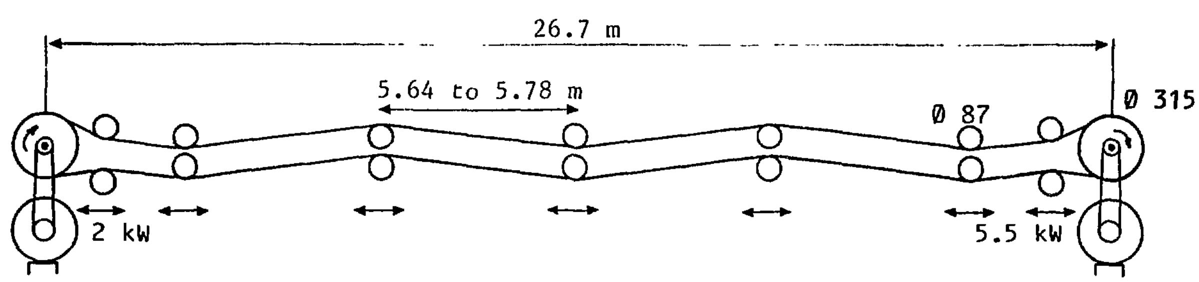
EXPERIMENTAL STUDIES

needed for :

- Collecting informations about the unknown Swedish belt characteristics
- Testing the mechanical behaviour of a 10 m/s, 50 m long conveyor with that belt
- Testing the electrical behaviour of the belt with such a different arrangement (decoupled structure, inside and outside rollers ...)

MECHANICAL TEST BENCH

One-to-one, half length (27 m) but with
no SF_6, no pressure, no voltage and limited power



Mostly confirmed theoretical design

BUT

showed mechanical problems with the test belt

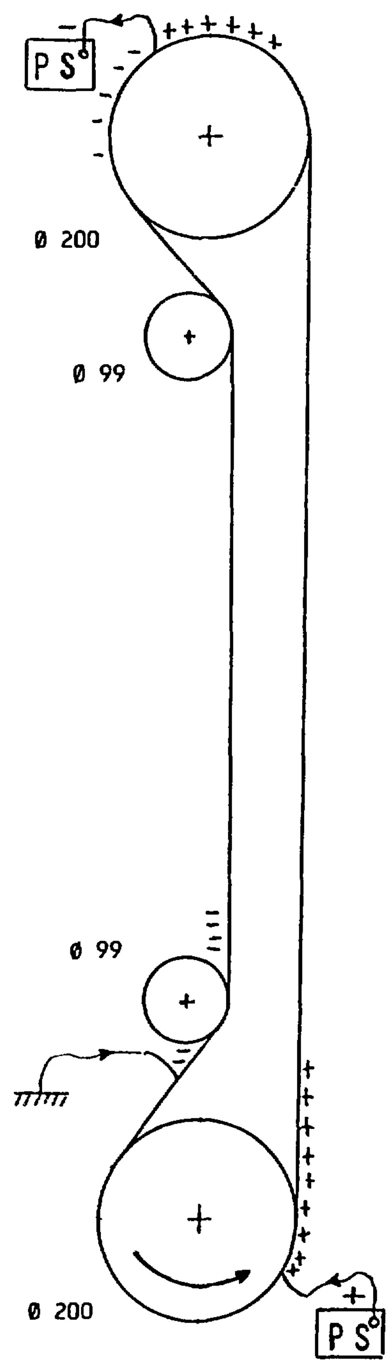
- Surface defects of the nitril coating
- Deformation due to defectuous manufacturing of the composite material together with rather loose fabric used
- Weakness of the splice which first slightly deteriorate then partly broke (after perhaps ~ 1500 hours)

E

7 MV CN PILOT MACHINE TESTS

1) MODEL OF THE INITIALLY DESIGNED CHARGING SYSTEM

- P ~ 5 KW
- v = 15.6 m/s
- T ~ 375 Kg-f per side
- Single drive
- Two 30° - 40° rollers



OBTAINED

- Scaled 200 μA (for 125) per side with 6.5 MV (for 35) voltage

BUT

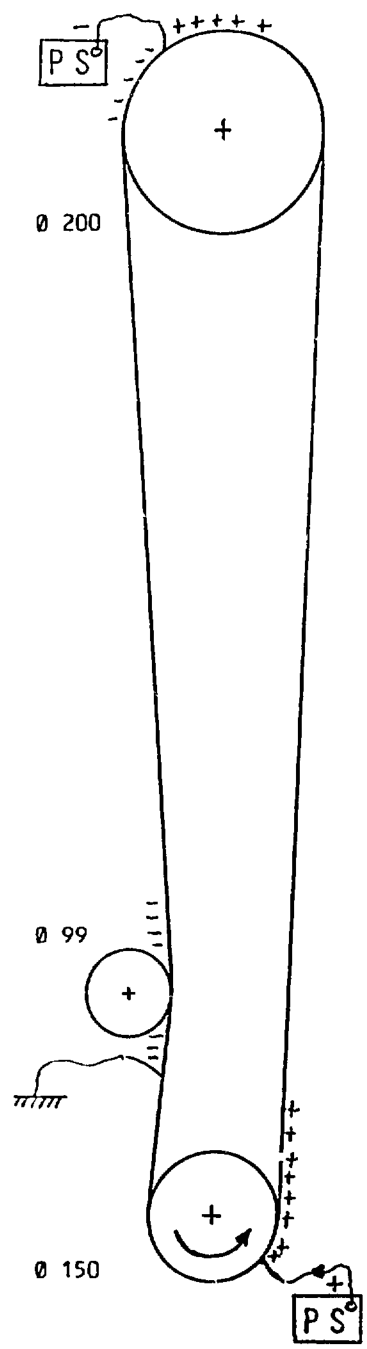
- High parasitic charge generation from rollers on the (outside) rubber face
- Early tear of the glued splice

Both caused by the counter flexion winding over small diameter rollers

7 MV CN PILOT MACHINE TESTS

2) MODIFIED TEST MODEL ARRANGEMENT

- P ~ 5 KW
- v = 10 m/s
- T ~ 520 Kg-f per side
- One 6° roller



OBTAINED
• Enhanced lifetime
• Lower parasitic charge generation

MAIN CHARACTERISTICS OF THE BELT

WENNERLUNDS

Mr. HELLEBOID Göteborg 1984-08-22

Tekniska Data

Refererande till dagens telefonsamtal översänder vi tekniska data för transportband typ WE 16/2 0+10 Nitril och WTO 25.

	WE 16/2 0+10 Nitril		HVEC 4-ply
	Given	Measured	Measured
Number of plies	2/polyester		
Cover thickness	Över : 1 mm nitril Under : Obelagd		
Tensile strength	160 Kp/cm	*160 kg-f/cm* *(90 at splice)*	*110 kg-f/cm*
Elongation at working load	1,5 % 16 Kp/cm Bandbredd	*1.6 %* *10 kg-f/cm width*	*0,6 %* *10 kg-f/cm width*
Total thickness	3.5 mm	*2,9 to 3,3 mm*	*2.6 mm*
Min. drumdiameter	100 mm		
Working temperature	- 25 to + 120°c		
Max. belt width	1600 mm		
Friction coefficient	Över : 0,5 - 0,6 Under : 0,15 - 0,2	*0,3 - 0,6* *0,15 - 0,2*	*both ~ 0,16*
Weight		*3,5 kg/m²*	*3,6 kg/m²*

MAIN CHARACTERISTICS OF THE CONVEYOR

ELECTRICAL

- Decoupled belt structure arrangement
- Charge density = 2.6 nC/cm^2 for I = 500 μA at 10 m/s
- Double up and down charge
- Four current regulated charging ioniser
- Only one grounded collection ioniser

MAIN CHARACTERISTICS OF THE CONVEYOR

MECHANICAL

- Conveyor length 50 m
- "Swedish" belt 100 m x 520 mm • 10 m/s speed
- Double drive by two 30 KW asynchronous motors
  coupled with the Ø 150 mm end pulleys
- One Ø 127 mm guide roller (6° counter winding) at HE end station
- Twelve Ø 89 mm (2200 r.p.m.) supporting rollers
  (four for the upper portion eight for the lower one)
- Two more Ø 112 mm rollers associated with
  two 4 KW Ø 190 mm generators into the terminal electrode
- 520 kg-f average tension per side (σ = 10 kg-f/mm of width)
  with which about 40 kW could be transmitted
- Extreme tensions being 435 and 605 kg-f per side
- For the ~ 33 kW required power including

The electrical power (35 MV x 500 μA)	17.5 kW
The gas friction power at 8 bars of SF6	3.5 kW
The mechanical losses (bearings + belt) ~	4 kW
The provision for power in the terminal	8 kW

FIRST TESTS OF THE REAL VIVITRON CHARGING SYSTEM

AFTER

- Precise optical alignement
- Careful tuning of the double drive, electronically controlled, starting unit

WAITING FOR SF_6 PRESSURE

Short circuited, air atmospheric mechanical tests

OBTAINED

- Good trajectory (only 5 mm apart from the axis over 50 m) easily tuned by less than 2 mrad adjustement of the HE roller and LE pulley
- Acceptable tracking (25 mm or less)
- Low induced vibrations

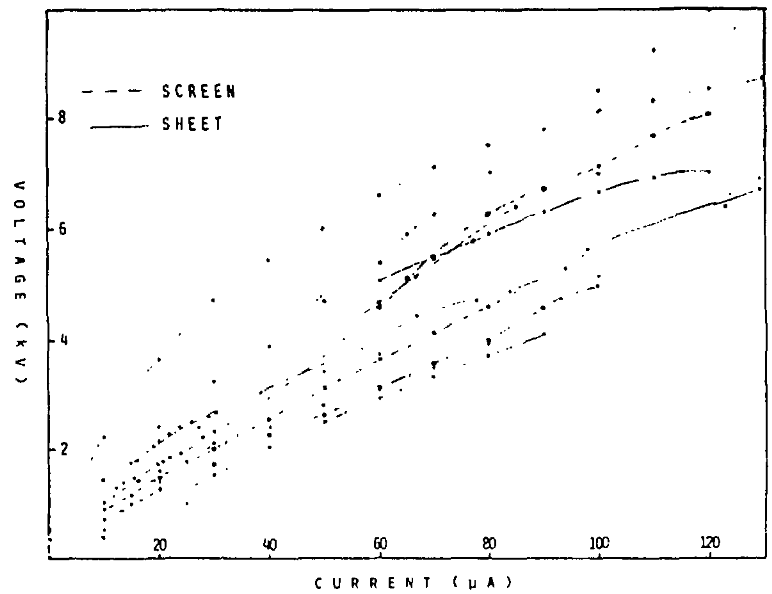
SCREENS vs SHEETS IONISERS

- 50 µm thick steel sheets
- Ø ~ 5 mil, 80 mesh stainless steel screens

SURFACE OF THE BELT

- Modified by the screens
- Almost no modified by the sheets

CHARGING PROCESS



COLLECTING PROCESS

Sheets less efficient than screens

Imprimé
au Centre de
Recherches Nucléaires
Strasbourg
1991