RECENT PROGRESS IN THE PERFORMANCE OF THE DESY-ELECTRON SYNCHROTRON

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D E S Y

Summary

During the first years of operation, primary emphasis was put on achieving reliability and stability. Of special note is the improvement in the slow extracted electron beams.
More recently, installation of a "flat top" giving us an improvement of duty cycle from 4.5 % to 15.4 % ($\Delta E/E = \pm 0.25$ %) has motivated us to emphasize increase of beam intensity. Intensity dependant instabilities have been encountered, studied, and to some extent cured.

Retrospect

At DESY the circulating electron beam was obtained for the first time in 1964. After 2 years of 5 day-per-week operation, i.e. since 1966, the accelerator is serving as a particle source for high energy physics in continous 3 shift-7 day-per-week operation. Figure No. 1 gives a table of operation hours for the years 1964 through 1972. Besides running for particle physics experiments, the first two years were mainly used to gain experience with the accelerator, train the operating crew, organize maintenance programs and cut down the break down rate by technical modifications. During this period the typical performance parameters were

max. energy 6 GeV,
average circulating current approx. 5 mA.

Aside from 4 photon beams, the first extracted electron beam was set up. The years from 1966 to 1970 were used for the first long term improvement program. The results were

more intensity
more stability
higher energy
improved quality of extracted electron and photon beams
even lower break down rate.

The max. intensity achieved (more than 16 mA average circulating current, which was the design intensity of DESY), and better beam stability, was mainly due to a large number of modifications on the 40 MeV injector linac. The experience, that a synchrotron is as good as its injector was proven true also for DESY. The linac modifications included a new gun and injection system, into which a prebuncher for the synchrotron radio frequency was incorporated. Also, the beam transport system used to inject the linac beam into the synchrotron was modified. The maximum energy was raised from 6 to 7.5 GeV by upgrading the radio frequency power to approx. 1 MW peak and 500 kW average power at 500 MHz, and by replacing the old stainless and epoxy vacuum chambers by alumina ceramic chambers. In order to generate a smoother photon beam spillout, the so-called high energy beam bump system was modified.
For the extracted electron beams, the extraction efficiency was brought up from the 10 to 40 % range to 50 to 85 %, whereas the vertical emittance came down from 1.5 πmm·mrad to 0.1 πmm·mrad, and the radial emittance from 2.5 πmm·mrad to 0.5 πmm·mrad. These results were achieved by moving the working point as indicated in Figure No. 2, thus avoiding the crossing of the $Q_r = Q_z$ line, and some 4th order resonances. Also, the current strip method was replaced by the "separate function" scheme, using separate elements like a quadrupole, a sextupole and a septum instead of one current strip doing all these jobs. The latest result of the studies on resonant extraction is the possibility of sharing the intensity of the rotating beam between two extracted beams at the same time. The ratio of intensity between the two beams is given by the relative position of the two septa, with respect to each other. Thus the high current intensity the synchrotron is now capable of accelerating can be used to serve two main users in parallel.
Since 1970 until now, the two main topics for our latest improvement programs were

installation of a flat top for the magnet field, and
operation at high intensities.

The flat top is generated by adding roughly 8 1/2 % of 200 Hz amplitude to the 50 cycle sine wave magnet excitation. This results in more than 3 msec time for an energy spread of

$$\Delta E/E = \pm 0.25 \%$$

instead of 0.9 msec for the normal 50 Hz sine wave excitation. Thus the duty factor went up from 4.5 % to 15.4 %, see Figure No. 3.
The task of providing a long and smooth spillout for photon and electron beams especially under flat top conditions, as well as the delicate requirements for controlling the slow extraction of two electron beams in parallel, necessitated a new scheme for the control of the closed orbit or the resonance conditions at the end of the acceleration cycle. Thus a feed back system was developed called a "self controlling signal generator". The total spillout time required is divided in 99 time bins. For each time bin the amplitude e.g. of a photomultiplier signal from the external beam is compared to the amplitude needed for an ideal signal, e.g. a square wave. Moreover, a digital storage unit is associated with each time bin. By a "learning" process needing several hundreds of machine cycles, the difference between the ideal wave form and the actual photomultiplier signal is made a minimum. The wave form thus delivered from the "self controlling signal source" then, in the case of a photon beam, controls a dipole current, which works in addition to a beam bump to control the localized closed orbit movement. In case of the electron beam, the signal source controls the current of an ac quadrupole lens, which brings the horizontal Q or ν-value to the 6 1/3 resonance. Figure No. 4 shows examples for both the photon and the electron beam application under flat top conditions. Figure No. 5 shows the present layout of beams at DESY, indicating also the possibility of complex schemes for parasiting.

Recent Improvements

The possibilities just indicated for beam sharing and parasiting, the improved methods for spillout control and last but not least the installation of the flat top have motivated us to increase beam intensity. As already mentioned, with the old 40 MeV electron linac we came up to 15 - 20 mA average circulating current at maximum, 10 mA being the routine value. In order to provide a source of positrons for the DESY storage ring project "DORIS", a new 400 MeV linac was installed. Of course this new linac also gave us a chance for a big step forward in electron intensity. The injection field is higher by a factor of ten, so that almost no corrections are needed anymore. The ß at injection is also higher, a 500 MHz chopper is used in the linac instead of a prebuncher, and the analysed current is higher. So it was possible to accelerate up to 30 to 40 mA average current without major difficulties. It is of special note that no losses occur during the first turns, or, in other words, that all particles are captured in stable phase. The ring filling originally was approx. 70 % and is now after improvement of the kicker being used for single turn injection approx. 85 %. So 30 to 35 mA average circulating current corresponds to roughly 40 mA peak injected current. Going higher with injected current, losses occurred after 1000 or 2000 turns (1 - 2 msecs) in the synchrotron. At very high injected currents, e.g. 150 mA, the losses start as early as after several dozens of turns, see Figure No. 6. Careful adjustments of the injection parameters like position and angle for the two directions, and amplitude and phase of the rf voltage, may slightly push up the intensity threshold by say 10 %, but they provided no basic cure. The instabilities caused a blow up of the radial beam profile mainly, and consequent loss of particles. Coherent oscillations both longitudinal and transverse were observed before and during the beam break up. After the reduction of intensity due to losses to the familiar 30 mA average value, these 30 mA could be accelerated all the way up to maximum energy. Since DESY has a complex high Q rf system consisting of 16 triple cavities fed from a resonant wave guide ring, our first studies concentrated on the interaction of the beam with this system. Without going through all details, I can summarize the result as follows: interaction between the beam and the complex rf system alone did not explain the instabilities. During the studies, 15 out of the 16 cavities were physically removed from the accelerator. For the remaining single cavity, amplitude and phase during acceleration were measured, the equilibrum phase was determined. Besides detuning, also two different settings for the transmitter-cavity coupling were tried. All operating conditions were carefully checked and found to be consistent with theory, but nevertheless the instabilities occurred, maybe at a slightly higher intensity threshold of approx. 50 mA peak injected current.

Thus, still operating with the single cavity system, a home made single octupole was tried to provide Landau damping. As shown in Figure No. 7, this proved to be rather successful. Approx. 100 mA peak/80 mA average current were accelerated all the way without instabilities showing up on intensity and position monitors. Also the beam profile stayed clean throughout the acceleration cycle, see Figure No. 8.

The octupole field had to be applied right at injection with only moderate strength. Thus, the octupole current could be dc, which is an easier technique than ac. Moreover, the octupole field influence gets less the higher the energy goes up in the acceleration cycle, which is helpful in that interference with extraction is thereby obviated. Figure No. 9 shows the way the coherence of transverse oscillations disappears faster due to the octupole field. The octupole then was tried also with first 8 then all 16 cavities replaced in the radio frequency system of the synchrotron. It turned out that the favorable influence of the octupole existed in these cases also. However, much more attention has to be paid to the injection parameters such as position and angle for the two transverse directions at injection, and rf amplitude. Moreover, in the 16 cavity case and at injected currents between 80 and 100 mA, the cavities have to be detuned by more than one bandwidth. In other words, everything has to be done to cut down the initial amplitudes for both transverse and longitudinal coherent oscillations. Under the special conditions indicated, 80 mA peak/65 mA average were obtained also with 16 cavities, i.e. the normal rf accelerating system. This is about 10 times our original intensity, and 4 times the original design intensity. Figure No. 10 gives a table of the main performance data of the DESY synchrotron as it is now.

Future Aspects

Let me conclude with some aspects for the future.

First: further improvements on intensity and beam quality.

Preliminary tests have shown, that active longitudinal and transverse feedback may be successful in helping to cut down the coherent oscillation amplitudes. Moreover, sextupoles will be tried against suspected head-tail effects. A single sextupole in our machine is not sufficient, since the built-in chromaticity is too large. With a combination of the methods mentioned it does not seem impossible to approach the 100 mA average current threshold for stable acceleration ($\hat{=}$ 6 x 10^{11} ppp $\hat{=}$ 3 x 10^{13} ppsec). As far as we can see this would meet almost all needs from the high energy physics side. Also, in a circular machine, there are other limits in operating with a 40 kW average power circulating beam.

Second: aside from trying to obtain even higher intensity and better beam quality as mentioned above, the synchrotron and the 400 MeV linac have to be prepared to serve as injector for the DORIS storage rings. The beam transport systems are well under way. However, we are trying to increase the positron intensity. Also means have to be provided for an adjustable number of bunches in the storage rings.

Third: Preliminary studies have shown that it would be desirable to store protons in DORIS to serve as a target for both electron and positron beams. Such an accomplishment would be useful both for physics directly and for studies on electron proton colliding beam facilities in general.

Because of its role as electron and positron injector for DORIS it seems natural to consider the DESY synchrotron also as an injector of protons. So investigations are under way to determine the necessary modifications for the electron synchrotron. Since no basic restrictions have shown up to so far, we hope that we can order a suitable proton source and start work on proton rf equipment and injection apparatus this year.

A separate paper in this conference (J.9)will deal with this project.

Acknowledgements

The work reported here represents the effort of the entire DESY synchrotron group. Special note is due to the contribution of the DESY power supply group in modifying the magnet power system for "flat top" operation. Also, the synchrotron group is indebted to Dr. Maury Tigner (Cornell) for his help and for fruitful discussions.

DESY S1	Total Running Time (h)	Time Scheduled for High Energy Physics	Useful Time for High Energy Physics
1964	1830	1009	767
1965	4675	3467	2592
1966	5530	4228	3461
1967	6816	4833	4367
1968	6968	5745	5137
1969	7160	5848	5574
1970	6456	5037	4854
1971	6384	5026	4431
1972	6876	5574	4978

Operation Statistics for DESY 1964 - 1972

Fig. 1: Table of Operation Hours 1964-1972

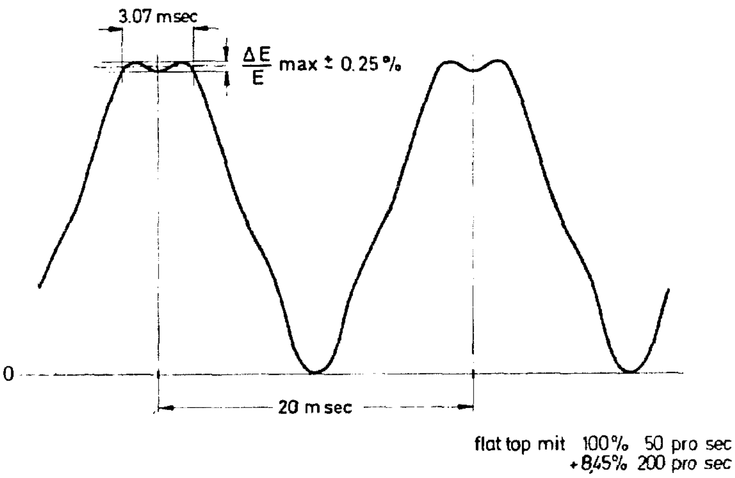
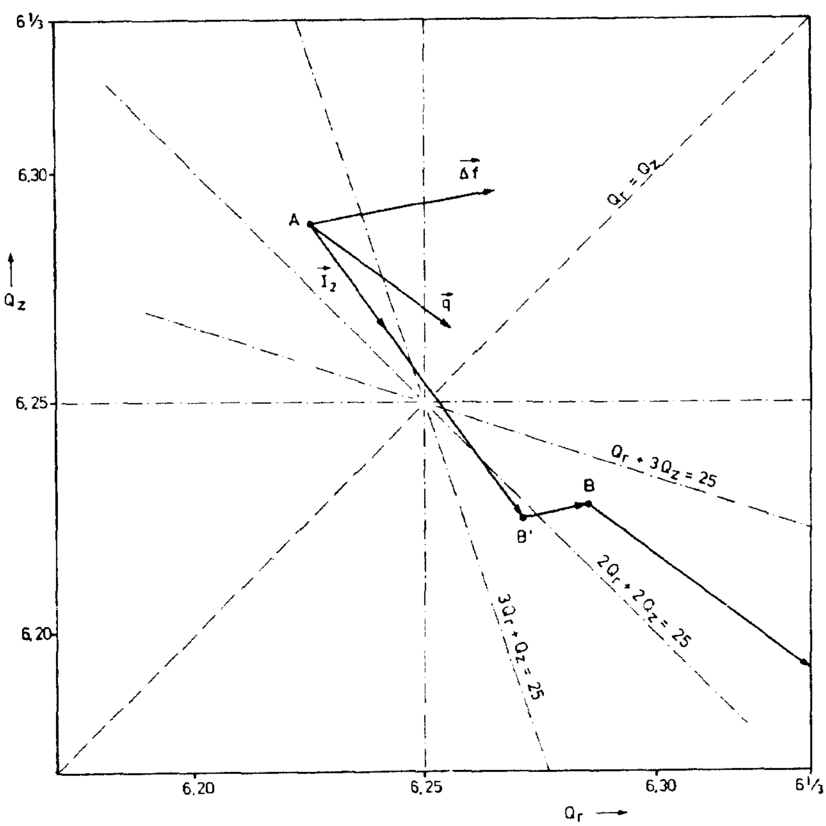


Fig. 3: Magnet Excitation for "Flat Top"



Working point for slow extraction using the "seperate function sheme"

$\vec{q}$	Regenerator or quadrupol
$\vec{\Delta f}$	Change of radiofrequency
$\vec{I_2}$	backleg windings
A	old working point
B	new working point

Fig. 2: Q_r/Q_z Working Point for Slow Extraction

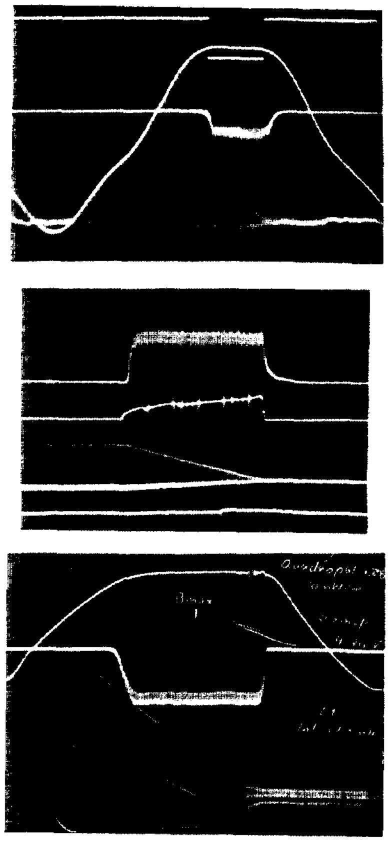


Fig. 4: Spillout Signals for Photon Beams and
Electron Beam Generated with the Help of
the "Self Controlling Signal Source"

Fig. 6: Intensity Dependant Instabilities

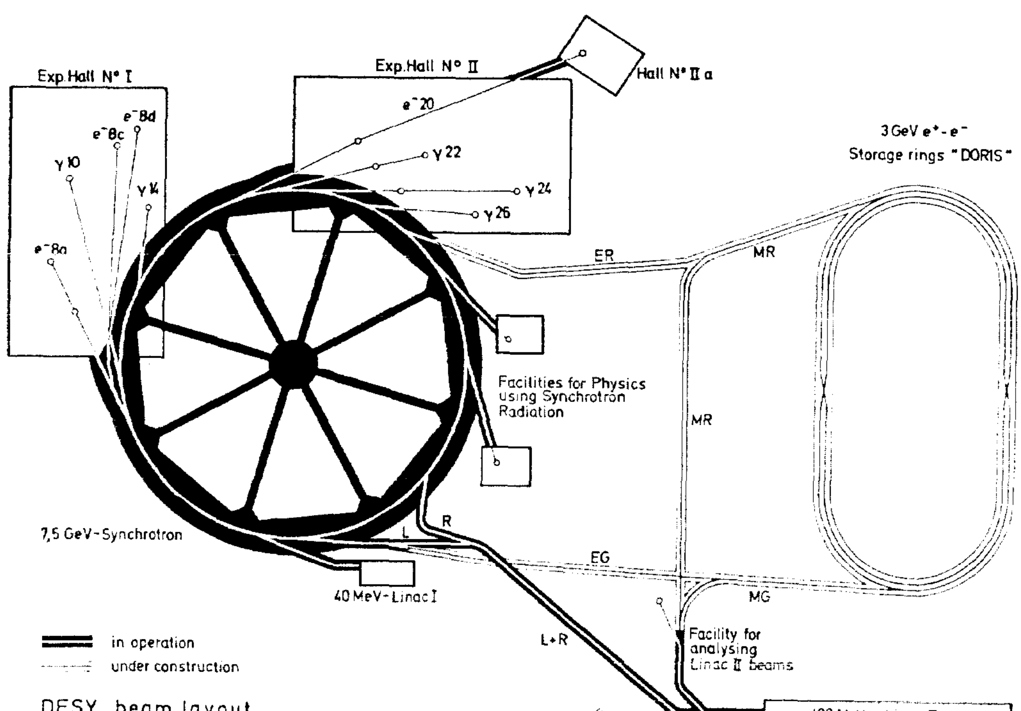


Fig. 5: Layout of Beams at DESY (End of 1972)

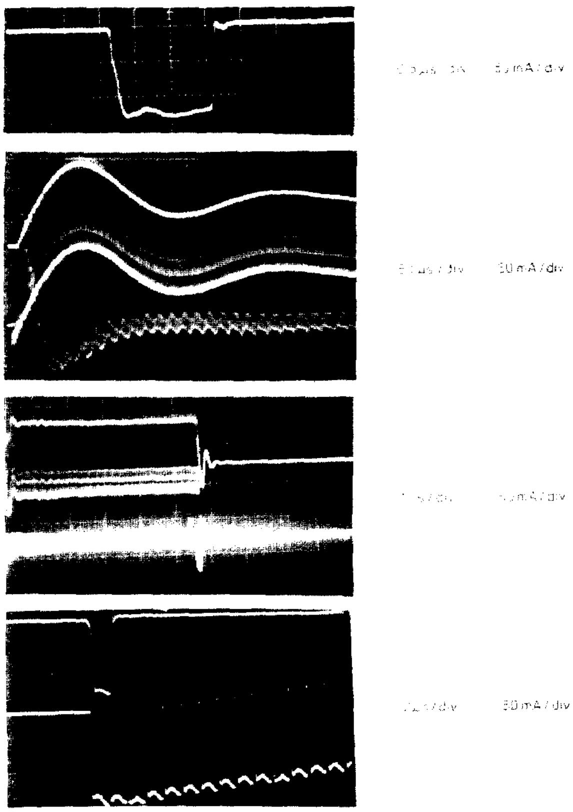


Fig. 7: Stable Acceleration of High Intensities with the Help of an Octupole

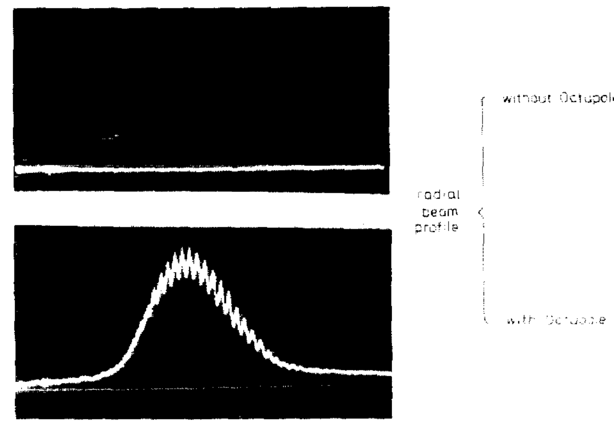


Fig. 8: Comparison of Radial Beam Profiles: without and with Octupole

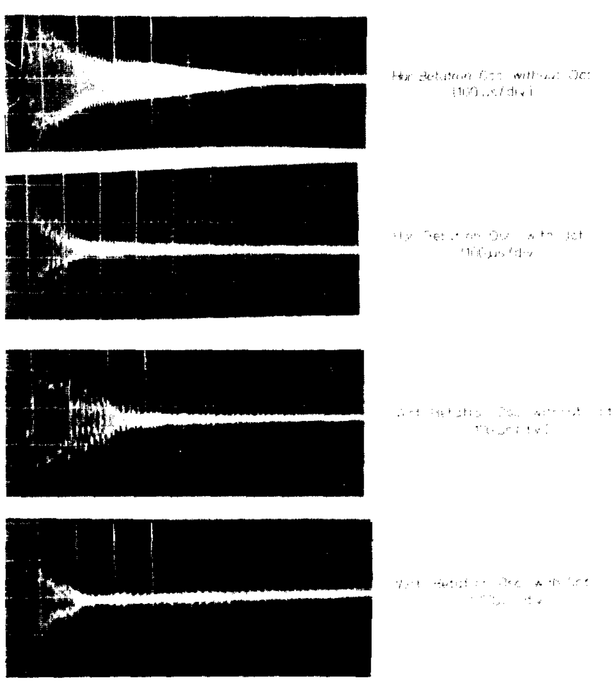


Fig. 9: Influence of Octupole on Coherent Transverse Oscillations

DESY PERFORMANCE PARAMETERS 1972

max. energy	7.5 GeV
pulse rep. rate	50 ppsec
max. macroscopic duty factor	15.4 %
resolution $\Delta E/E$ (used for definition of duty factor)	$\pm$ 0.25 %
internal electron beam	65 mA average or $4 \cdot 10^{11}$ ppp or $2 \cdot 10^{13}$ ppsec or 4 µA equ. dc
internal positron beam	0.65 mA average or $4 \cdot 10^{9}$ ppp or $2 \cdot 10^{11}$ ppsec or $4 \cdot 10^{-8}$ A
external electron beam	
energy range	1 to 7.25 GeV
max. intensity (at 25 mA av. circulating beam)	10^{11} ppp or $5 \cdot 10^{12}$ ppsec
beam emittance	$\varepsilon_z \approx 0.1 \cdot \pi \cdot$ mm $\cdot$ mrad $\varepsilon_r \approx 0.5 \cdot \pi \cdot$ mm $\cdot$ mrad
extraction efficiency	50 % < η < 85 %
extraction time (for $\frac{\Delta E}{E} = \pm 0.25$ %)	0.3 msec < t_e < 3.1 msec
external positron beam	$2 \cdot 10^{9}$ ppp or 10^{11} ppsec
number of beams	2 external e^+/e^- beams (also simultaneously) 3 photon beams 2 converted photon beams for test purposes 2 synchrotron radiation beams

Fig. 10: Performance Data for DESY (End of 1972)