INVESTIGATION OF NON-LINEAR BEAM DYNAMICS WITH APPLE II-TYPE UNDULATORS AT BESSY II

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Abstract

APPLE II-type undulators are common sources of light with variable polarization. At BESSY II the UE56 insertion devices (IDs) consist of two parts. The closing of the upstream parts leads to an intolerable lifetime reduction of the beam.

The paper describes the experimental investigation of this effect. Lifetime and beam loss measurements as a function of the working point clearly revealed the excitation of many resonances and especially a skew octupole driven resonance as the cause for the reduced lifetime. The non-linearity stems from remaining field errors. In addition to existing bench measurements the integrated fields of the ID were determined with beam-based techniques. Skew and normal multipoles could be extracted from measurements of the vertical beam kick and the tune shift with horizontally displaced orbits inside the ID.

Right now the impact of the ID on the lifetime can only be reduced by staying away from excited resonances. In future APPLE-type IDs a better control of the magnet block inhomogeneities is required.

1 INTRODUCTION

In the near future up to 4 APPLE II-type IDs[1] for the production of synchrotron light with variable polarisation will be installed in the 1.7 GeV storage ring BESSY II[2]. Two IDs of that type are already used in routine operation with full magnetic gaps down to 16.6 mm. The UE56 IDs consists of an upstream and a downstream part of 30 periods each with a period length of 56 mm[3]. They are placed symmetrically to the middle of the straight section where $ß_x$=14 m, $ß_y$=3.5 m, and $\alpha_x=\alpha_y=0$. The compensation of the linear effects introduced by the ID did cause no problems, since gap and shift variations are done slowly. The orbit distortions as well as the tune shifts[4] are compensated for by feed forward techniques. Opposite to expectations[3,5], especially the upstream parts have a severe negative impact on the lifetime of the stored beam. The following sections will focus on the non-linear effects introduced by the ID.

2 OBSERVATIONS

Fig. 1 shows, as a function of the vertical tune, the impact of the two parts of the UE56ID3R (located in the D3 straight section) on the lifetime and the particle losses at the limiting vertical (small gap ID vacuum chamber) and horizontal (septum magnet) apertures[6]. On the nominal working point (Q_x=17.84 and Q_y=6.72) the closing of the upstream part severely shortens the lifetime. At other tunes the lifetime is reduced by 10 or 20 % when the downstream, respectively the upstream, part is closed. The loss rates in comparison to the lifetime show a very similar behaviour. Since the determination of the lifetime is rather time consuming in the following experiments beam loss detection was preferred in order to speed up the measurements.

Vertical tune scans as a function of the magnetic gap of the upstream part of the UE56ID6R are shown in Fig. 2. Only at very small gaps many new resonance lines pop up. Up to a gap of 25 mm no additional impact of the ID is observed. The results presented in Fig. 1 and Fig. 2 were obtained with the shift parameter set to zero. In this case the ID acts like a conventional planar undulator and

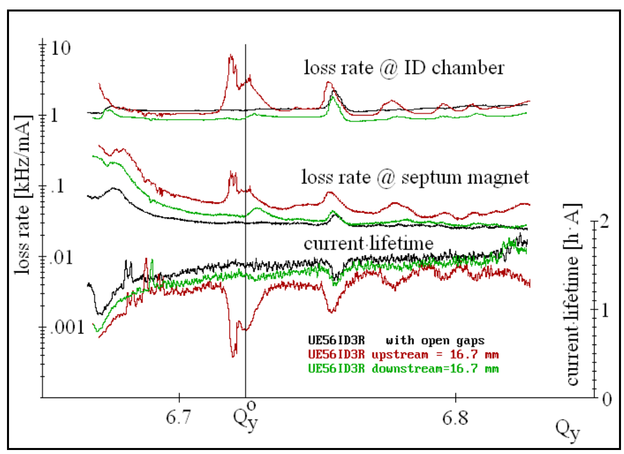

Fig 1. Lifetime times current and the loss rates as a function of the vertical tune. The horizontal tune was kept fixed at it’s nominal value. The lifetime is severely limited due to the upstream part of the ID.

the wiggling motion lies in the horizontal plane. Fig. 3 shows, that the shift parameter has no strong impact on the beam dynamics. Resonance lines are independent of the shift of the two opposing rows of magnets, however, since the horizontal tune does change, some of the resonances appear slightly shifted or broadened because lines do overlap.

Two dimensional tune scans around the nominal working point were performed in order to find out which resonances are excited and which resonance is responsible for the dramatic reduction of the lifetime. In Fig. 4 results are shown with the ID gap open and closed. The upstream

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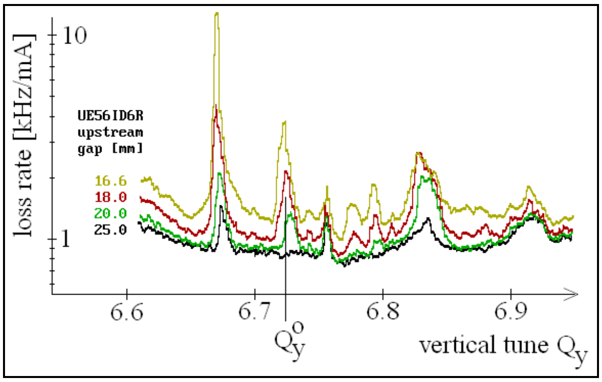

Fig. 2: Loss rates as a function of the vertical tune and the magnetic gap of the upstream part of UE56ID6R.

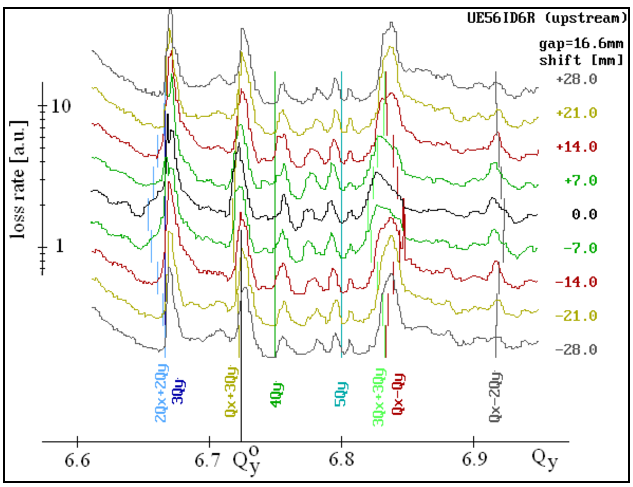

Fig. 3: Impact of the shift parameter (upstream part of UE56ID6R) on the loss rates as the vertical tune is varied.

part excites many new resonances or enhances existing ones. The most harmful is the Q_x+3·Q_y-resonance driven in lowest order by a skew octupole field component.

From the different effects produced by the nominally identical parts of the UE56ID3R shown in Fig. 1 it is obvious, that the observations can not be attributed to systematic effects but relate to individual field errors of the parts. Also in case of the UE56ID6R the upstream part influences the beam dynamics more strongly than the downstream part.

3 FIELD ERRORS

Integrated field errors of the IDs obtained by bench measurements with a stretched wire as a function of the horizontal displacement did show rather strong variations between data points spaced by 2.5 mm. Depending on the number of data points and the degree of the polynomial used for the fit, no trust worthy development regarding multipole components was possible. In principle, the resonance-like features presented in the previous section could be used in connection with tracking calculations in order to estimate the ID related non-linear field

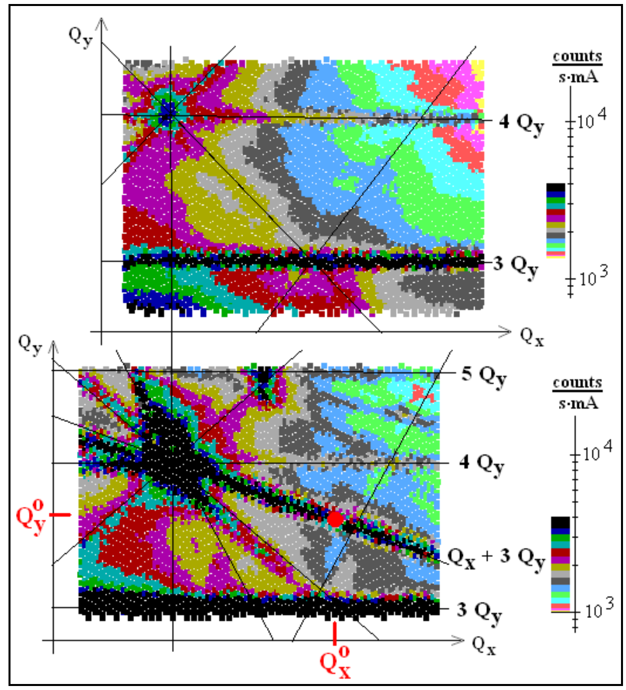

Fig. 4: Two dimensional tune scan without (top) and with the upstream part of the UE56ID3R closed (bottom). The most perturbing resonance Q_x+3·Q_y is clearly visible. The ID contains a large number of non-linear field components and thus many resonances are excited.

components. This was not done, instead a more direct beam-based technique was chosen.

The integrated vertical as well as the horizontal fields were estimated from the tune shift and the vertical orbit distortion recorded as a function of the horizontal beam position relative to the centre of the ID. The orbit displacement was created with a closed orbit bump. Since the beam had to be moved horizontally stepwise by up to +15 and -15 mm the bump stretched into the neighbouring bending sections where the chromatic sextupole magnets are located. During the experiment all harmonic sextupole magnets, placed in the straight sections, were turned off and the horizontal beam position outside the bump was kept fixed by the slow closed orbit feedback system[7]. The orbit feedback also keeps the energy constant which is important for the tune measurements.

The integrated horizontal (skew) field was obtained by analysing the vertical orbit distortions in terms of an additional vertical kick produced by the ID. The integrated vertical (normal) field as experienced by the beam can be extracted from the tune measurements. In both cases a series expansion was fitted to the recorded data and the net effect of the ID is given by the difference between the expansion coefficients with and without the gap closed. The vertical field is obtained by integrating the series over the horizontal displacement of the beam.

The results of the tune measurements and the extracted integrated field errors are shown in comparison with the straight line integrals from moving wire measurements in

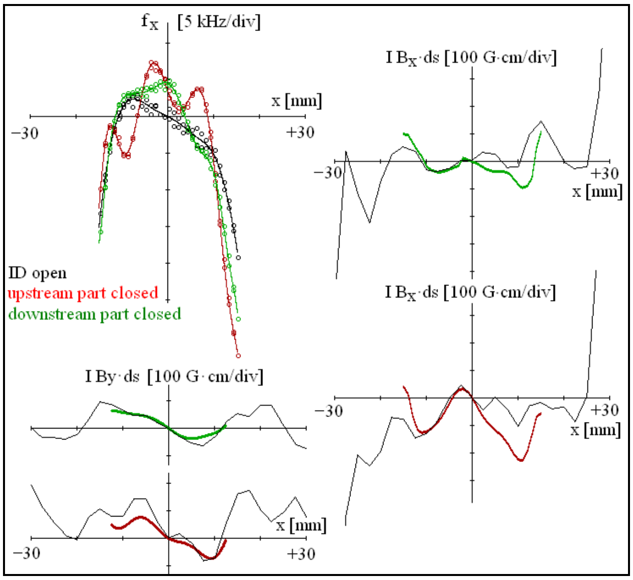

Fig 5: Beam-based measurements of the integrated field errors in comparison with results obtained by a stretched wire (black). The results for the up- and downstream parts are shown in red and green.

the left of Fig. 5. Note the oscillations of the horizontal tune as a function of the position with a period length of 10 mm. Systematic block inhomogeneities add up coherently to large field integrals and the discrete size and position of the required shims lead to an oscillatory behaviour of the remaining field errors. The agreement of the final results with the bench measurements is acceptable. For the vertical or skew fields, shown in the right side of Fig. 5, large discrepancies are found for positive horizontal orbit offsets in the upstream part.

The resulting skew multipole field components obtained by the beam-based measurements have been used for the determination of the dynamical apertures with tracking calculations. The skew octupole component of 1100 m^{-3} is able to reproduce the observations close to the $Q_x+3{\cdot}Q_y$-resonance. The vertical field shown in Fig. 5 changes slopes very rapidly, so by moving the beam sideways the skew multipole components should change dramatically. In Fig. 6 for a few components this variation is shown together with the measured lifetime as a function of the vertical tune. A few mm of horizontal displacement leads to strong variations of the skew octupole, and sextupole components, and of the corresponding resonances. The measurement can be used to specify upper bounds of multipole components in case more suitable specifications of field errors are not at hand. Obviously the beam dynamics does depend strongly on the cumulative effect of all field components. The lifetime is generally shorter for off-centred beams.

4 SUMMARY

The unexpected influence of the APPLE II-type undulator on the beam lifetime can be attributed to uncompensated field errors of the ID. In principle these problems can be solved. Re-shimming of one ID was partly successful and has reduced the impact of the most harmful resonance. In any case, more refined compensation schemes or a better control of the inhomogeneities is essential[2]. In the future more work is required and planned in order to understand the discrepancy between the beam-based and the stretched wire measurements of the integrated skew fields. For the time being the working point has been moved away from the skew octupole driven $Q_x+3{\cdot}Q_y$-resonance and the lifetime reduction by the APPLE II-type IDs was lowered to the 10 - 20 % level.

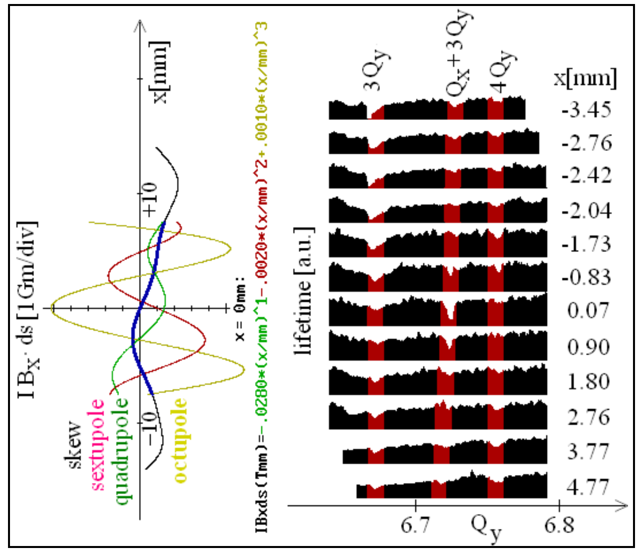

Fig. 6: Some lower skew multipole components as a function of the horizontal beam position inside the ID (left) and corresponding lifetimes vs. vertical tune (right).

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