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CCDTL POWER SPLITTING

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SUMMARY

In the final version of the powering scheme for Linac4, it is foreseen to have four klystrons for the 7 modules of the CCDTL.

In this note we report the possible configurations that can be set with the four klystrons and its impact on the beam dynamics performances.

INTRODUCTION

In the final version of the powering scheme for Linac4 [1] (see Figure 1) it is foreseen to have four klystrons for the 7 modules of the CCDTL (2.8 MW each). With this scenario two different configurations can be envisaged, either feeding the last module or the first module with one klystron. The nomenclature followed in this note is “LM” for the first option and “FM” for the second one, as shown in Figure 2.

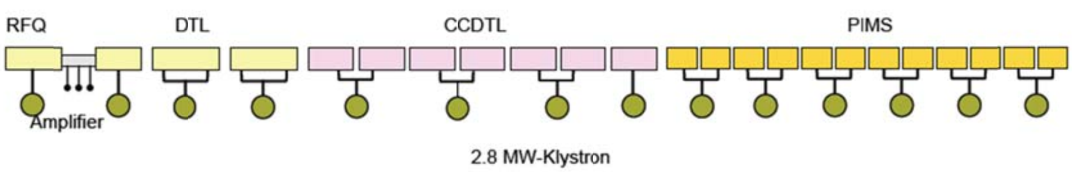

Figure 1: Powering scheme for Linac4, phase II.

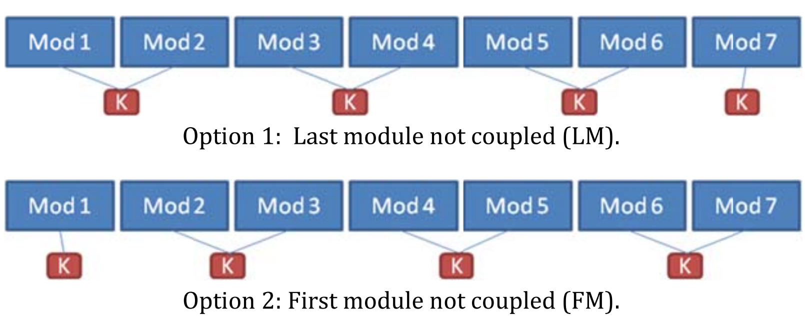

Figure 2: Possible powering configurations for the CCDTL.

When two modules are coupled, the power is divided between the two by a power divider which, however, cannot provide a perfectly equal power splitting. The two modules will therefore operate at a different cavity voltage from the one simulated for the nominal beam dynamics: a percentage of the nominal voltage is added to one module whereas in the other the same percentage is subtracted, keeping the average constant. Depending on the voltage difference between the two modules, the nominal beam dynamics can be compromised.

The aim of this note is therefore to report the error studies campaign launched in order to:

a) Determine the better klystron powering scheme in terms of beam dynamics performances;
b) Define the relative difference in field that could be acceptable between two modules fed by the same klystron.

EFFECT OF POWER SPLITTING ERROR AT THE CCDTL OUTPUT

The beam dynamics parameters mainly affected by the power imbalance between two adjacent modules are the longitudinal emittance and the output energy. For this reason 500 linacs were randomly generated for each configuration and with the following values of maximum imbalance: 5%, 7%, 10% and 15%. The particles were tracked along the CCDTL with the code PathManager [2]. The results are plotted in Figure 3. In all cases the transmission is 100%.

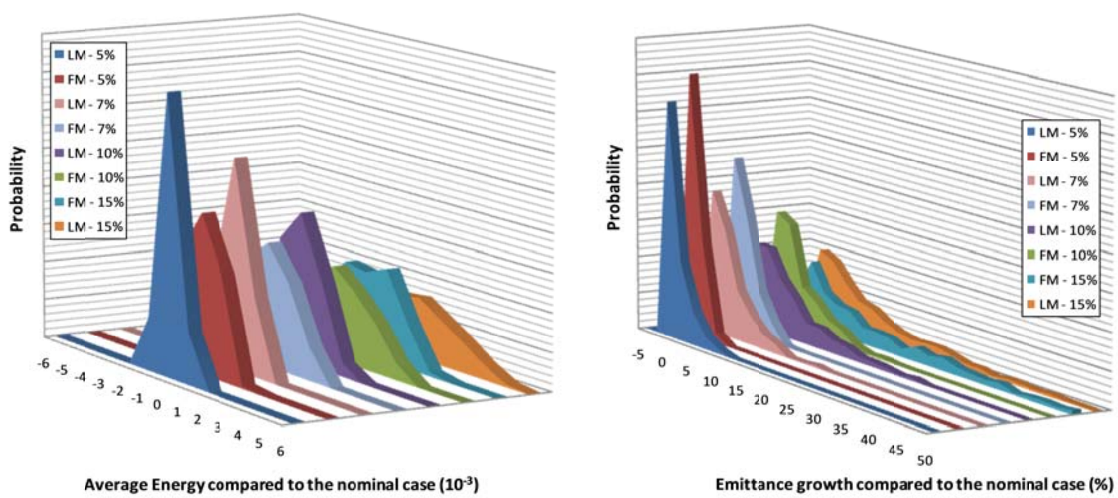

Figure 3: Probability results of 500 linacs randomly generated for 5%, 7%, 10% and 15% maximum voltage unbalance for both LM and FM options.

As could be predicted, the bigger the error the more the beam quality at the end of the CCDTL is affected. This is due to the longitudinal mismatch caused by the voltage error. Since the first module plays a fundamental role in matching the beam into the following ones, the better option is having the first module powered independently. Regarding the average output energy, the effect is the opposite because the first module gives the least energy boost among the modules.

In order to fix a limit to the maximum voltage imbalance which could be accepted, the cumulative probability of the longitudinal emittance growth is plotted in Figure 4. If the maximum tolerable emittance increase at the end of the section is fixed at about 10 % (99 % probability), the maximum voltage error is 5 % for the LM and 7 % for the FM option. If the limit is slightly relaxed, 7 % for the LM and 10 % for the FM option could be accepted.

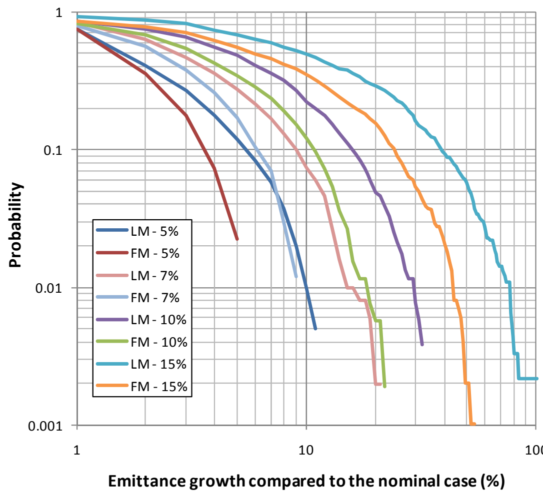

Figure 4: Cumulative probability in log-log scale for the 2 options as function of the maximum voltage imbalance.

The error on the output energy in shown in Figure 5, where the Gaussian fit of the histograms of Figure 3 is plotted. The LM option is less sensitive to the power imbalance, but the absolute value for both options is very low and it will barely affect the beam dynamics in the PIMS.

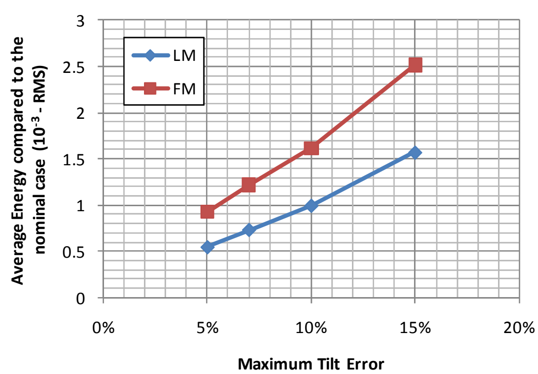

Figure 5: Average energy growth compared to the nominal case as function of the imbalance values.

In order to consolidate the results obtained, 7 % LM and 10 % LM were run at the maximum acceptable imbalances mentioned before adding phase errors within ±0.5 degrees (maximum tolerance). In Figure 6 the results are shown: as expected the phase jitter broadens the probability distribution for both options by a few percents only.

The same comparison was done for the output energy and it is shown in Figure 7. The distribution width is maintained whereas its center is slightly shifted toward a lower energy by less than one per mill.

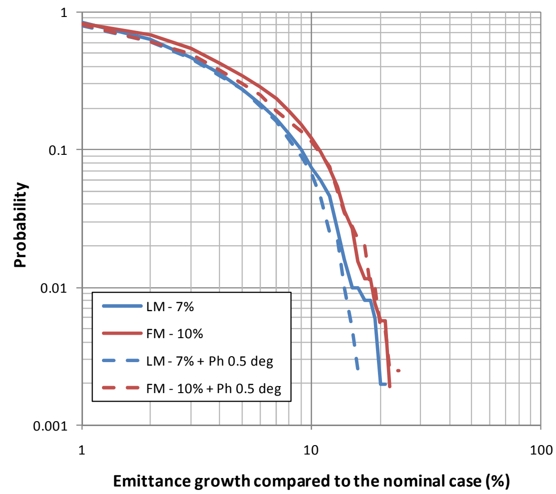

Figure 6: Cumulative probability in log-log scale for the 2 options at the maximum accepted value without and with the ±0.5 degrees phase jitter.

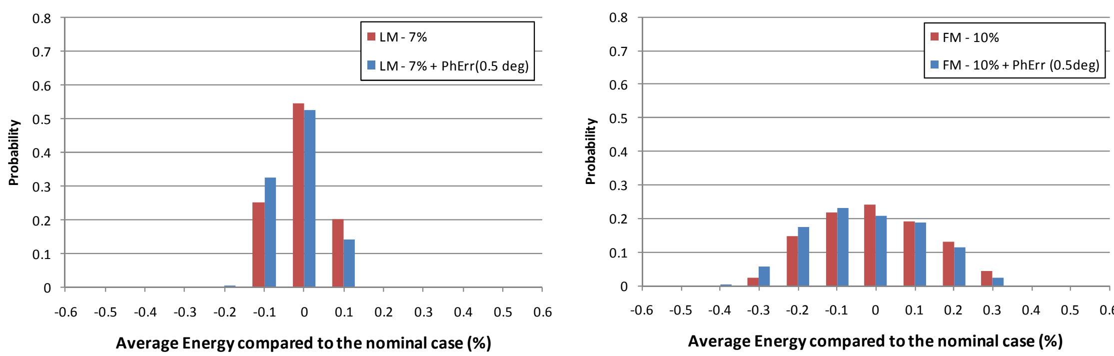

Figure 7: Energy growth for the 2 options at the maximum accepted value without and width the ±0.5 degrees phase jitter.

EFFECT OF POWER SPLITTING ERROR AT THE PIMS OUTPUT

The studies were continued downstream the CCDTL to observe the beam characteristics at the output of the PIMS. The PIMS section was simulated without any error on voltage or phase.

A comparison between the results already obtained in the previous section and the probability distribution of the emittance growth after the PIMS is reported in Figure 8. The PIMS section amplifies the mismatch generated in the CCDTL and consequently the longitudinal emittance increases. On the other side the relative error on the output average energy becomes smaller (see Figure 9) since the energy gain in the PIMS does not depend strongly on the input energy.

The result of this study is that the limit fixed above cannot be accepted at the end of the linac as an output emittance increase of more than 20% (99 % probability) is not tolerable. Therefore an additional error studies campaign was launched to see whether, assuming the worst cases for the field imbalance, the longitudinal emittance growth could be reduced and the output energy compensated.

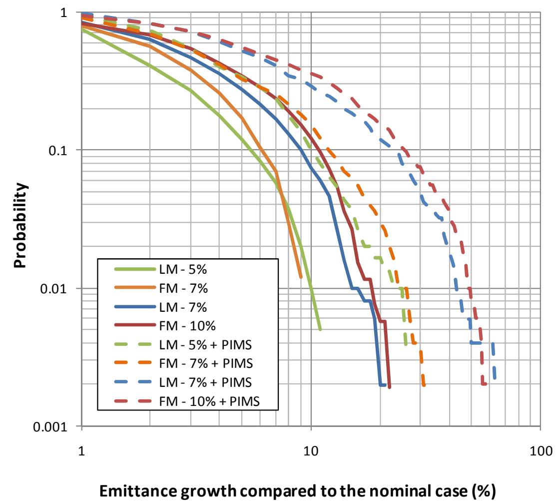

Figure 8: Cumulative probability in log-log scale for the 2 options at the CCDTL and PIMS output.

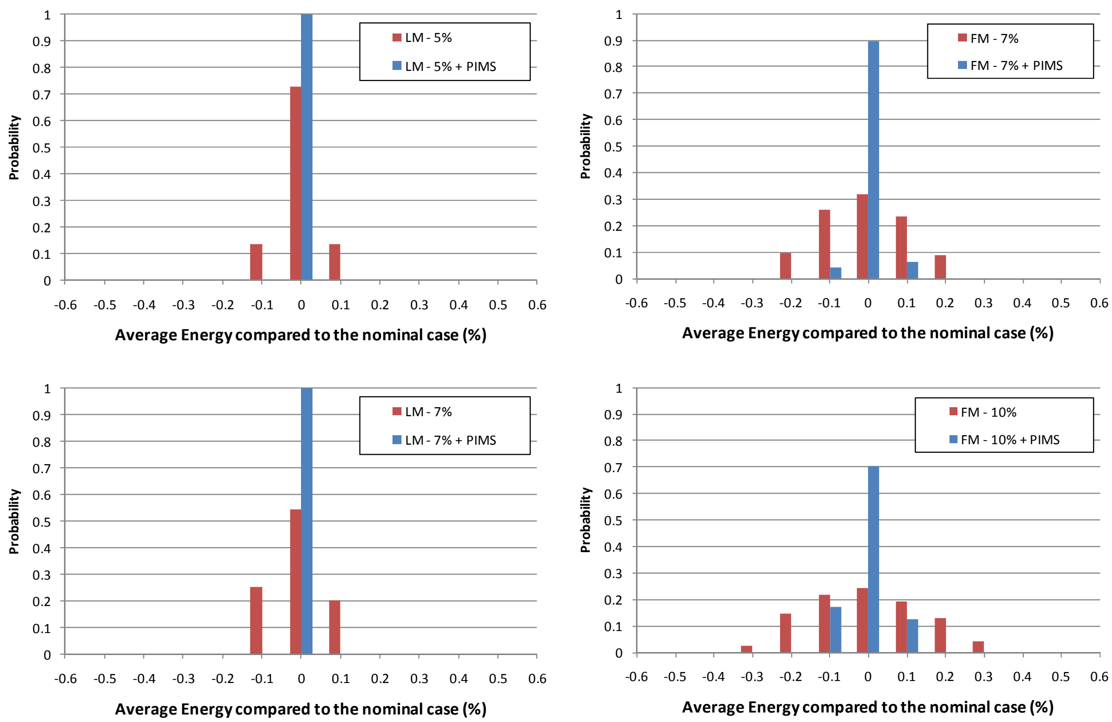

Figure 9: Comparison of the percentage of energy growth respect to the nominal case at the CCDTL and PIMS output.

This optimization was carried out changing randomly the synchronous phase of the 7 modules within ±5 degrees. Actually this procedure means finding a new longitudinal beam dynamics of the CCDTL for the actual cavity voltage by trial and error.

The results of this error study (200 runs) are shown in Figure 10: the starting points lie in the center of the plot but the runs are distributed uniformly on the entire plot area. This means that it is possible to find a new CCDTL working condition, which would reduce the mismatch at the PIMS input. The beam dynamics results reported in Table 1 show that the configuration of the synchronous phases which minimizes the longitudinal emittance growth and compensate the average output energy reduces the mismatch factor defined in [3] as well.

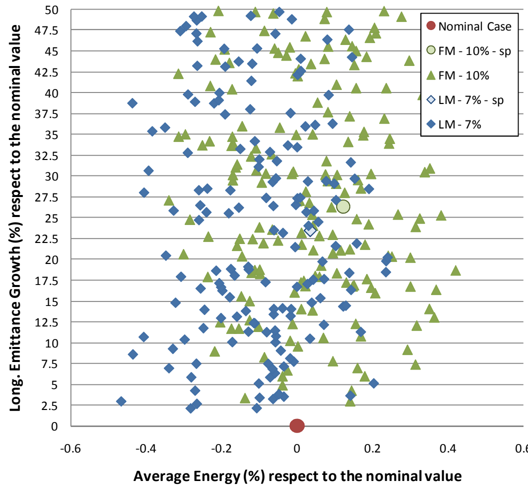

Figure 10: Longitudinal emittance growth as function of the Average energy growth with respect to the nominal value varying the phase by max ±5 %. The starting points (sp) refer to the worst cases without re-phasing.

Table 1: Beam dynamics results at the end of the CCDTL and PIMS after synchronous phase optimization. In brackets the values before optimization.

	At the CCDTL output			At the PIMS output		
	% Average energy growth	*% Long. Emit. growth*	*Mismatch factor*	*% Average energy growth*	*% Long. Emit. growth*	*Mismatch factor*
LM – 7%	-0.06 (0.03)	3.25 (23.4)	0.09 (0.78)	-0.02 (0.00)	4.32 (46.7)	0.16 (0.39)
FM – 10%	0.14 (0.12)	3.02 (26.3)	0.07 (0.46)	0.04 (-0.03)	3.64 (90.8)	0.13 (0.48)

From these studies it can be concluded that even for worst voltage imbalance chosen as acceptable in the first section (7 % LM, 10 % FM) but then revealed unacceptable at the end of the PIMS, the beam dynamics can be optimized by means of a CCDTL re-phasing.

Conclusions

FM configuration is the one that in the presence of errors has the minimum longitudinal emittance deterioration under any conditions.

In both cases the effect on the final average energy is within the PIMS acceptance.

Assuming a tolerance of 20% in the longitudinal emittance growth, 7% of power imbalance for the LM configuration could be accepted and 10 % for the FM option. In any case a re-phasing of the CCDTL is necessary to avoid out of tolerance longitudinal emittance growth at the PIMS.

Operationally this re-phasing will be an empirical procedure and it is not clear how to set it up. In order to avoid it, if a LM configuration is chosen, the difference in cavity voltage between two coupled modules must be better than 5%.

REFERENCES

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[2] Perrin and J. F. Amand, Travel v4.07, users manual, CERN (2003).

[3] T. Wangler, "RF Linear Accelerators", pp. 217-218.