SL/BT Internal Communication
April 28,2001
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Proposed Orbit Correction Configuration for the CNGS Line

The orbit correction system configuration for the CNGS line has been evaluated and optimised within constraints allowed by space and cost using an analytic program. Design optics is used in the program to establish generalised response matrices. The latter are then used to project various error distributions arising from injection, magnetic field, alignment and monitor offset errors according to design tolerances, in order to obtain global, quantitative measures on different performance criteria of the system, such as observability, correctability, correction range, response singularity etc.. Abilities to quantitatively compare localised configuration changes and to decompose offending cases into their error contributions allow the optimisation process to be carried out at a finer level. The program has also been used to effect incremental improvements on the configuration through a well-defined path.

Of particular concern to the CNGS line are the tolerances on the exit angles. The program calculates the 3σ exit angle envelope for a given configuration in addition to the 3σ orbit envelope over the entire line, extended to the target, thus providing the 3σ error-induced envelope for the complete phase space of the orbit.

The configuration presented here is the outcome of systematic optimisation taking into account the above performance requirements. The baseline scheme consists of 10 BPM's and 10 correctors in each plane, interleaved to allow intuitive one-to-one steering. An alternate (over-constrained) scheme, assuming the availability of a generic SVD type of steering software, skips every other corrector in the periodic section and achieves a more balanced underlying corrected orbit profile. The important performance measures are summarised graphically in Figures 1 through 8, which show the 3σ underlying corrected orbit envelope for the entire line, and corrector range scaled by the σ of the error distribution. The 3σ values for the underlying corrected exit angles are also displayed. Table 1 gives a brief summary of the 2 schemes.

As the saving in total number of correctors is not significant in the alternate scheme, it is recommended that the baseline scheme be implemented to expedite steering in the commissioning phase when steering software may be unavailable. The configuration can then be switched to the over-constrained scheme once the line is commissioned and software-aided steering becomes routine.

		Orbit / Angle envelope	BPM / CORR	
Baseline scheme	1-to-1	X: <<2.2 / 0.05, 2 peaks @ 3.1 Y: <<2.3 / 0.077, 2 peaks @ 3.2	10 / 10 10 / 10	Corr. limit : 1 H (inj.) 1 V (inj.) Orbit envelope on target <1 mm HV
Alternate scheme	Over-constrained	X: 2.3 / 0.05, 1 peak @ 2.7 Y: 2.4 / 0.077, 2 peaks @ 2.9	10 / 7 10 / 8	Corr. limit : 1 H (inj.) 1 V (inj.) Orbit envelope on target <1 mm HV

Table 1 Configuration and Performance Summary

cngs_elem0_errh_NGH_MCHA_MO_testX
Maximum underlying corrected orbit at all–elem

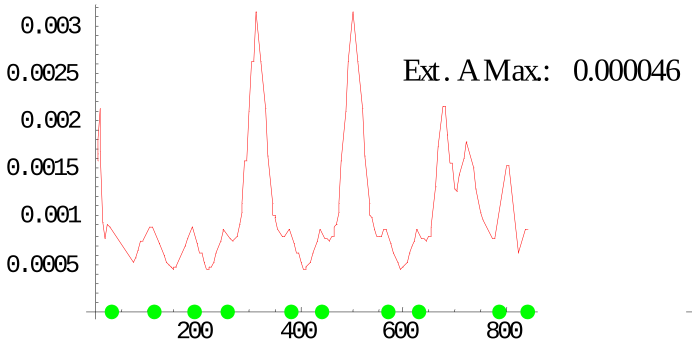

Figure 1

cngs_elem0_errh_NGH_MCHA_CD_testX
Corrector range in units of projected sigma

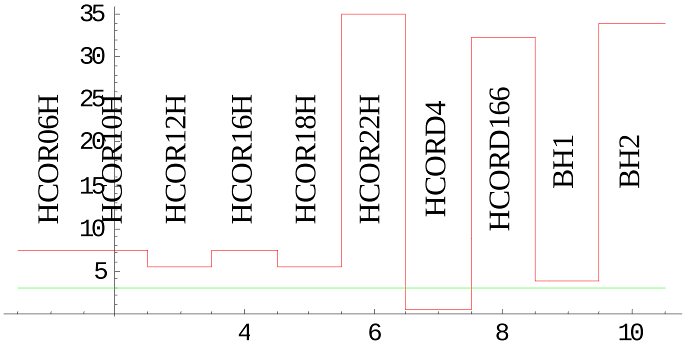

Figure 2

cngs_elem0_errv_NGH_MCHA_MO_testY
Maximum underlying corrected orbit at all–elem

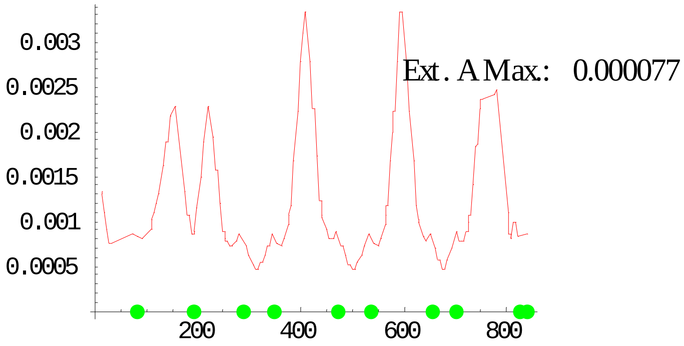

Figure 3

cngs_elem0_errv_NGH_MCHA_CD_testY
Corrector range in units of projected sigma

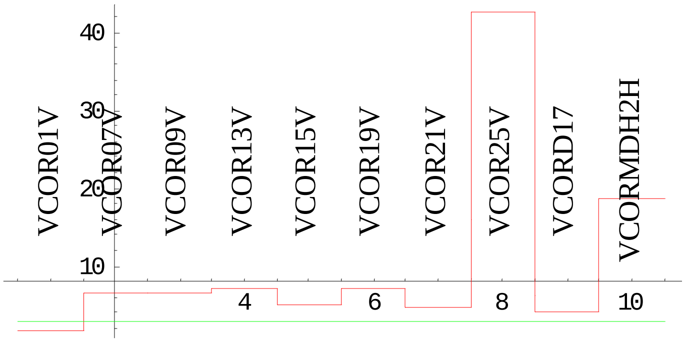

Figure 4

cngs_elem0_errh_NGH_MCH_MO_testX
Maximum underlying corrected orbit at all–elem

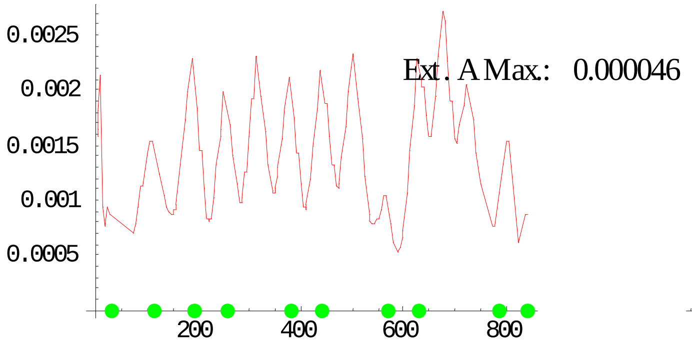

Figure 5

cngs_elem0_errh_NGH_MCH_CD_testX
Corrector range in units of projected sigma

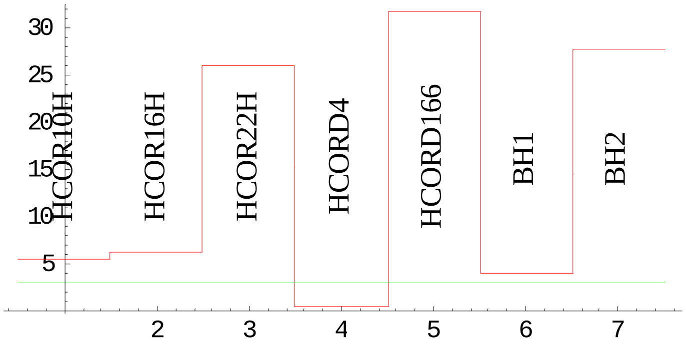

Figure 6

cngs_elem0_errv_NGH_MCH_MO_testY
Maximum underlying corrected orbit at all–elem

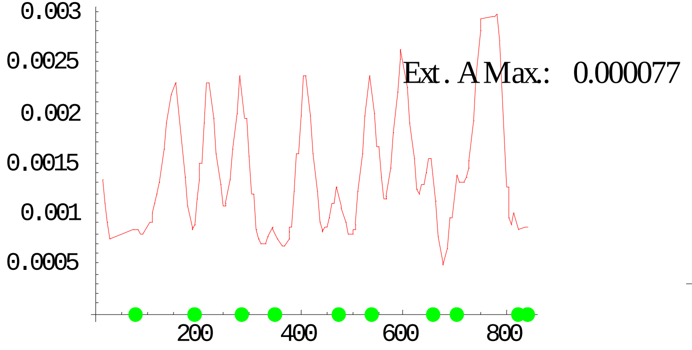

Figure 7

cngs_elem0_errv_NGH_MCH_CD_testY
Corrector range in units of projected sigma

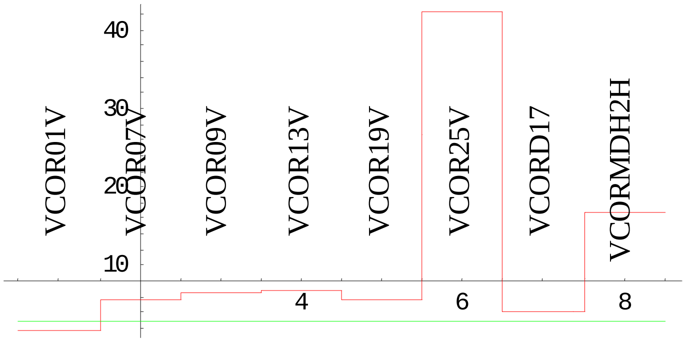

Figure 8

An effort was also made to identify critical monitors and correctors, which uses as a measure the adverse impact on orbit error envelopes due to various failure modes. The five leading critical elements for each failure mode in each configuration are listed in Table 2. Most of the large numbers seen in Table 2 reflect artefacts of trivial configuration singularities or boundary effects, which can be summarised as follows:

In all 1-to-1 steering schemes, a missing monitor would immediately lead to a singular steering configuration and excessive correction can result if handled improperly. In such cases disabling one corrector would resolve the problem[1]. This applies also to the non-periodic sections of the over-constrained steering schemes, where the steering is actually 1-to-1. This can be demonstrated in the over-constrained scheme, where steering with BP11 in the horizontal plane missing leads to orbit peaks of 1.2 m due to such singularity. By disabling the corrector VCOR13 the peak is reduced to around 3.5 mm. Similar solutions work for most of the other large numbers in Table 2 due to missing monitors.

Some cases on the other hand are not easily remedied with disabled correctors. These cases fall under two categories: Sensitivity to injection and high β near the end. The first happens in the vertical steering with BP03 missing. The problem in this case is caused more by either phase anomaly or inability to contain large injection error. Disabling either of the adjacent correctors does not completely address the injection problem, although in the over-constrained case it does eliminate the singularity and reduce the artificial peak from 1 m to 16 mm. The second case involves the missing BP26 in the horizontal steering. Since this is the critical BPM at a β of 300 m, it absence leads to problems not easily compensated. Thus these two BPM's play the most critical roles operationally in ensuring proper orbit behaviour, in both the 1-to-1 and the over-constrained schemes.

The large orbit peaks associated with individual monitor offset errors cannot be dismissed as artefacts, but should be regarded as potential sources of orbit correction problem. Prioritised preventive measures, such as BPM alignment and calibration, should be taken with these numbers in mind.

Almost all significant orbit peaks associated with missing correctors come from a single source: insufficient leverage in fixing injection errors. With the first vertical corrector VCOR01V situated at a low β point due to space constraints, this problem is more severe in the vertical plane. This has been obvious from the plots of corrector range in units of error σ's shown in the previous Figures showing VCOR1V and HCORD4 short of being capable of containing 3σ errors. Solution to this problem lies in horizontal orbit control upstream of the injection point and enhanced vertical corrector range or upstream orbit control.

The limited correcting power for fighting injection errors is also responsible for the sensitivity of the orbit error to the correction process. This explains the large orbit peaks associated with corrector scaling errors being all caused by the same correctors responsible for fixing injection error. Again this sensitivity can be fixed only by orbit control upstream of the injection point.

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[1] A more effective algorithm for solving this problem can be found in **Error! Reference source not found.**.

Disabled Monitor		**Fixed Monitor Offset of 3 mm**		**Disabled Corrector**		**Fixed Corrector Scale Error of 50 %**	
Baseline (1-to-1) Horizontal							
BP04	23.37 (a)	BP12	6.02	HCORD4	4.73	HCORD4	31.01
BP06	13.19 (b)	BP06	6.00	BH1	3.53	BH1	24.88
BP26	8.77 (c)	BP26	5.50	HCOR10H	3.49	HCOR18H	7.50
BP02	4.75	BP18	4.08	BH2	3.41	HCOR10H	4.96
BP18	3.41	BP14	3.99	HCOR12H	3.38	HCOR22H	4.73
Baseline (1-to-1) Vertical							
BP03	6.36 (d)	BP06	7.24	VCOR01V	15.50	VCOR01V	9.06
BP17	3.35	BP15	6.22	VCOR13V	3.65	VCOR07V	3.96
BP11	3.34	BP09	6.22	VCOR07V	3.47	VCOR09V	3.90
BP09	3.33	BP21	5.00	VCOR15V	3.34	VCOR13V	3.85
BP06	3.33	BP03	4.93	VCOR09V	3.34	VCORD17	3.73
Alternate (Over-Constrained) Horizontal							
BP18	18.34 (e)	BP26	5.54	HCORD4	4.76	HCORD4	31.04
BP26	11.36 (f)	BP18	4.40	HCOR22H	4.15	BH1	25.01
BP02	4.76	BP12	3.77	HCOR10H	4.03	HCOR10H	6.08
BP20	4.53	BP20	3.75	BH1	3.62	HCOR22H	5.76
BP14	4.39	BP14	3.72	HCOR16H	3.00	BH2	3.72
Alternate (Over-Constrained) Vertical							
BP11	1198.71 (g)	BP06	7.24	VCOR01V	15.50	VCOR01V	9.06
BP03	1009.63 (h)	BP03	4.93	VCOR07V	4.03	VCOR07V	4.01
BP06	748.01 (i)	BP15	4.80	VCOR19V	3.57	VCOR19V	3.91
BP09	4.65	VBPMD173	4.61	VCORD17	3.27	VCORD17	3.34
BP17	4.64	BP21	4.02	VCOR13V	3.19	VCOR09V	3.33

(a). Peak becomes 4.1 mm by disabling HCOR06H.

(b). Peak becomes 6.0 mm by disabling HCOR06H.

(c). This can not be easily remedied due to very high βx.

(d). This can not be easily further reduced due to sensitivity to injection error

(e). Peak becomes 3.6 mm by disabling HCOR16H.

(f). This can not be easily remedied due to very high βx.

(g). Peak becomes 3.5 mm by disabling VCOR13V.

(h). Peak becomes 16 mm by disabling D17V or VCOR1V, still susceptible to sensitivity to injection error.

(i). Peak becomes 3.1 mm by disabling D17V.