# RHIC Insertion Concepts 

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#### Abstract

In this note, we analyzed several new concepts in the RHIC insertion design. We found that (1) Lattice can be tuned to obtain a mini- $\beta$ insertion. However, the required quadrupole aperture QX1 and QX2 may be too large, due to the crossing angle, to reach the gradient needed for the mini- $\beta$. To obtain a more realistic gradient achievable mini-insertion layout, we also solve the insertion matching with fixed gradient and determine the length of the mini-insertion common quadrupoles(see Appendix). It turns out that the available free experimental area becomes $\pm 3.6 \mathrm{~m}$. (2) A conventional or superferric magnet may be used to replace the BC1 as part of the detector system. This option requires an 8 mX 1.76 T field strength at 840 Tm . The length of this BC1 precludes the possibility of mini $\beta$ insertion in this configuration. Based on these two options, we concluded however that the lattice design is not the most effective way of reaching higher luminosity due to inherent nature of flexibility of operational modes. It is therefore more important to consider other options, such as improving the source, increasing the number of bunches, or stochastic cooling in order to control the growth of the beam due to the intrabeam Coulomb scattering.


## I. Introduction

The users in the second RHIC workshop pointed out some of the following features may be important to the upgrade of the RHIC design:
(1) Higher intensity is helpful and important for certain experiments, while smaller diamond length is very important.
(2) The detector size is about $\pm 6 \mathrm{~m}$ derived from the workshop design.
(3) BG1 may be used as a spectroanalyzer.

These features indicate that several possible new concepts can be incorporated into the present IR design. Following table lists the parameters of IR design in the present configuration.

| Free space | $\pm 10 \mathrm{~m}$ |  |
| :---: | :---: | :---: |
| BC1 | 3.3m @4.63T | $20 \mathrm{~cm} \mathrm{coil} \mathrm{i.d}$. |
| Drift(BC1-BC2) | 5.3m |  |
| BC2 | 4.4m@2.73T | 10 cm coil i.d. |
| Crossing angles | 0 mrad 7 mrad |  |
| Operational $\beta$ | $\begin{aligned} & 6 \mathrm{~m} @ 30 \mathrm{GeV} / \mathrm{amu} \\ & 3 \mathrm{~m} @ 100 \mathrm{GeV} / \mathrm{amu}^{+} \end{aligned}$ |  |

$\& \mathrm{~B} \rho=840 \mathrm{Tm}$
$+\beta^{*}=2 \mathrm{~m}$ may be operable at $100 \mathrm{GeV} / \mathrm{amu}$.

Based on the demand of the user's group, there are a few possible considerations for the IR region to be discussed in the following. In section 2, we shall discuss the mini- $\beta$ insertion, i.e. a pair of quadrupoles will be located between the interaction point and BC1 to reach an even smaller $\beta^{*}$. We discuss a more realistic mini- $\beta$ insertion design in the appendix. In section 3, we analyze the option of using conventional magnet for BC1. This option may be important to experiments, which use BC1 as a spectroanalyzer. However this option excludes the possibility of a mini- $\beta$ insertion.

## II. Mini- $\beta$ insertion in RHIC

To reach a highest intensity in the RHIC, a pair of quadrupoles located between BC1 and the experimental detector may be used to obtain a matched smaller beta functions for the interaction point. Figure 1 shows the present configuration of the IR region with the common quadrupoles for the mini- $\beta$ insertion.


Fig. 1 Geometric configuration of MINI insertion

In the norminal insertion, there is no common quadrupoles between BC1's. The distance between the BC1 and the interaction point is $\pm 10 \mathrm{~m}$ free space for the expermental instrumentation. The mini- $\beta$ insertion requires an extra-pairs of quadrupoles shown in Fig.l. The free space available becomes $\pm 6.5 \mathrm{~m}$. Table 1 lists the lattice properties in the insertion region for the mini- $\beta$ insertion. The beam size requirement ( $6 \sigma$ ) is calculated, for the normalized emittance of $\epsilon_{\mathrm{N}}=33 \pi-\mathrm{mm}-\mathrm{mrad}$ and $\mathrm{dp} / \mathrm{p}=1.2 \cdot 10^{-3}$ at $100 \mathrm{GeV} / \mathrm{amu}$ for Au ion at 10 Hours of operation. Figure 2 shows the betatron function at straight section. Figs. 3 and 4 show the beam size at the straight section for $100 \mathrm{GeV} / \mathrm{amu}$ and $30 \mathrm{GeV} / \mathrm{amu}$ respectively.

In comparison with the norminal insertion at the same maximum $\beta$ function of 400 m , we would expect an enhancement factor of $3.13 / 2.06 \approx 1.5$ to the luminosity in comparison with the standardard insertion. This enhancement factor can be increased up to 2 , i.e. the $\beta^{*}$ is tuned to 1.5 m , where the betatron function at BC2 becomes about the size of 350 m . Assuming a 10 cm coil i.d. for $B C 2$, the beta-value of 350 m has reach the dynamical aperture limit for $B C 2$. Thus the enhancement factor of 1.5 to 2 can be obtained by the mini- $\beta$ insertion layout. Table 2 lists also the ratio of the beam size to the magnet coil aperture. The ratio measure the magnitude of nonlinearity experienced by the beam.

Tracking study indicates that 2 out 6 interaction points can be operated at $\beta^{*}=3 \mathrm{~m}$ without the mini- $\beta$ insertion at $30 \mathrm{GeV} / \mathrm{amu}$. At $30 \mathrm{GeV} / \mathrm{amu}$, the ratio at Q 2 and Q 3 is about 0.75 . If the tracking result is correct, then the mini- $\beta$ insertion can also be operated at $30 \mathrm{GeV} / \mathrm{amu}$ with $\beta^{*}=2 \mathrm{~m}$. At this $\beta^{*}$ value, beam size ratio at $B C 2$ is also about 0.75 . It is however clear that the
mini- $\beta$ insertion can not give an enhancement factor of 2 at 30 GeV because of the aperture limitation at BC2.

Table 1. Betatron function in the interaction region.


Figure 5 shows the betatron function in the entire insertion region. The phase advance per insertion is increased by $0.05 \cdot 2 \pi$. The tune of the machine can be readjusted by the phase advance of arc cells. Table 2 lists the quadrupole strength requirement in the mini- $\beta$ insertion. For 0 degree crossing, the aperture requirement for magnets X 1 and X 2 is 60 mm coil i.d. for a 10 hours $30 \mathrm{GeV} / \mathrm{amu}$ operation. If the mini- $\beta$ insertion is only intended for $100 \mathrm{GeV} / \mathrm{amu}$ operation, the SSC 40 mm coil i.d. magnet may be used. To incorporated with the crossing angle up to 7 mrad, The coil i.d. requirement of magnet X 2 becomes 130 mm for 100 GeV /amu operation or 160 mm for 30 GeV /amu operation. The gradient requirement is about $190 \mathrm{~T} / \mathrm{m}$ for a .5 m long magnet. I can imagine the difficulty of this magnet. As a reference, The 130 mm coil i.d. magnets of Q1-Q4 require a gradient of $57 \mathrm{~T} / \mathrm{m}$.

Table 2. quadrupole strength for mini- $\beta$ IR

|  | LQ(m) | inner <br> $\mathrm{K}\left(\mathrm{m}^{-1}\right)$ | outer <br> $\mathrm{K}\left(\mathrm{m}^{-1}\right)$ |
| :--- | :--- | :--- | :--- |
| $\mathrm{X1}$ | 0.5000 | 0.1217 | 0.1217 |
| X 2 | 0.5000 | 0.1127 | 0.1133 |
| G1 | 1.5107 | 0.1170 | 0.1170 |
| G2 | 2.4209 | 0.1626 | 0.1625 |
| G3 | 1.1225 | 0.0703 | 0.0703 |
| G4 | 0.8327 | 0.0628 | 0.0632 |
| G5 | 1.2531 | 0.1127 | 0.1128 |
| G6 | 1.1916 | 0.1201 | 0.1201 |
| G7 | 1.6037 | 0.1354 | 0.1353 |
| G8 | 1.4168 | 0.1179 | 0.1179 |
| G9 | 1.0344 | 0.0843 | 0.0843 |

From the ratio of table 1, it is clear that RHIC may be operated at higher $\beta$ function at Q2 and Q3. Recent tracking calculations ${ }^{3}$ indicate that RHIC may be operated at $\beta^{*}=2 \mathrm{~m}$, where $\beta_{\max } \simeq 625 \mathrm{~m}$. This gives beam size to the magnet coil i.d. ratio of
0.6 for Q2 and Q3. In this case, the natural chromaticity becomes -70 . Thus the sextupoles need extra $23 \%$ of strength to correct the chromaticity. If only two-family of sextupoles are needed in the chromatic correction, the $23 \%$ of extra strength is included in the sextupole design. This require further studies.

Based on the above assumption that $\beta^{*}=2 \mathrm{~m}$ is operable, the mini- $\beta$ insertion can give 50\% increase in luminosity. Thus we can expect to have a factor of 2 in luminosity from this operational mode.
III. Conventional magnet for BC1

If the experimental set up requires only $\pm 6 \mathrm{~m}$ of free space, it is interesting to use the conventional or superferric magnet for the BC1 suggested by G. Cottingham. In this case the magnet can be used easier for the dual purposes of beam crossing dipole as well as spectroanalyzer. Fig. 6 show the crossing geometry in this configuration. The following table gives relevant parameters.

$\& B \rho=840 \mathrm{Tm}$
$+\beta^{*}=2 \mathrm{~m}$ may be operable at $100 \mathrm{GeV} /$ amu.

As we have mentioned earlier, this insertion layout excludes the possibility of mini- $\beta$ insertion. However it gain a very important feature of customizing the BC1 for experimental purposes.

## IV. Conclusion.

We have analyzed serveral possible features of different insertion layout (see table 3). We found that the mini- $\beta$ insertion can only give enhancement factor of $1.5 \quad 2$ in the luminosity. This is largely determined by the BC2 aperture. On the other hand, RHIC may be operated at $\beta^{*}=2 \mathrm{~m}$ at $100 \mathrm{GeV} / \mathrm{amu}$ without the mini- $\beta$ insertion. With the mini- $\beta$ insertion, RHIC may be operated at 11.5 m of $\beta^{\text {n }}$. Thus the luminosity may be a factor of 23 in comparison with that of the RHIC proposal. Magnets X1 and X2 may be difficult to be manufactured due to the large crossing angle requirement.

Table 3. Performance comparison between Norminal \& MINI insertion

|  | Norminal_Insertion - . MINI Insertion |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| Energy (GeV/amu) | 30 | 100 | 30 | 100 |
| Operable $\beta^{*}$ (m) | 3 | 2 | $2^{+}$ | 1.5 |
| Maximum $\beta$ (m) | 400 | 625 | 400 | 625 |
| Performance limitation | Q2-Q3 | Q2-Q3 | BC2 | QX2, Q |

+ See the discussion for the difficulty in BX1-BX2

On the other hand, when the luminosity is not a critical issue, an conventional or superferric BC1 magnet is very attractive option as well. In this case, the ${ }_{*}$ Iuminosity can not be increased by mini- $\beta$ insertion. However $\beta^{*}=2 \mathrm{~m}$ may still be operable.

Besides the above mentioned options, there are a few other concepts:
(1) Move BC1-BC2 unit forward 3m so that the first quadrupole is located at 21 m instead of 24 m in the present configuration. The luminosity in this case is increased only $20 \%$.
(2) Move BCI-BC2 unit backward so that a set of triplet to obtain the small $\beta^{*}$. This option has a few drawback as well.
a. The triplet are common quadrupoles for colliding beams. Thus they can not be used for the unequal species. The luminosity for the unequal species collision will be low.
b. The BC1 would encounter large $\beta$ function and require even larger magnet paerture.
c. Aperture limitation for the crossing angle is even larger.

Because of these limitations, the later options are not studied further.

Based on the present study, we conclude that the lattice may not be the best option for higher luminosity operation in RHIC. It
would more fruitful to study the following problems, Source improvement feasibility of increasing the number of bunches Stochastic cooling feasibility

## Appendix:

To obtain a realistic mini-insertion quadrupoles, we shall assume a constant transfer function of having $B^{\prime} / B^{\prime}=19.325 \mathrm{~m}^{-1}$ similar to the RHIC regular quadrupoles and then search for a solution of mini- $\beta$ insertion with allowable quadrupole length. The length of these mini- $\beta$ quadrupoles are $L Q X 1=1.5925 \mathrm{~m}$ and $\mathrm{LQX} 2=1.3117 \mathrm{~m}$. The free insertion space becomes $\pm 3.6 \mathrm{~m}$ or 7.2 m . In this configuration, the lattice can be tuned to 1.5 m without much impact on the beam size in the insertion region. The quadrupole strength is given in table A.1 and the lattice function is given in Table A. 2.

Table A.I Quadrupole strength $\left(\mathrm{m}^{-1}\right)$ in the MINI insertion LQX1 $=1.5925 \mathrm{~m} \quad$ LQX2 $=1.3117 \mathrm{~m}$

| $\beta^{*}(\mathrm{~m})$ | 2 |  | 1.5 |  |
| :---: | :--- | :--- | :--- | :--- |
| Quads | Inner | Outer | Inner | Outer |
| K1 | 1.0000 | 0.9990 | 1.4098 | 1.4099 |
| K2 | 1.0000 | 1.0063 | 1.3478 | 1.3464 |
| G1 | 1.0243 | 1.0240 | 1.0443 | 1.0436 |
| G2 | 0.8382 | 0.8376 | 0.8075 | 0.8076 |
| G3 | 0.7338 | 0.7331 | 0.6871 | 0.6869 |
| G4 | 0.9219 | 0.9266 | 0.9429 | 0.9445 |
| G5 | 1.1333 | 1.1358 | 1.1666 | 1.1699 |
| G6 | 1.2838 | 1.2849 | 1.4632 | 1.4634 |
| G7 | 1.0625 | 1.0636 | 1.0766 | 1.0766 |
| G8 | 1.0254 | 1.0259 | 1.0342 | 1.0338 |
| G9 | 1.0275 | 1.0286 | 1.0343 | 1.0304 |

+ The length of quadrupoles Q1-Q9 are obtained via. the standard insertion layout.

The essential problem in the mini-insertion scheme is the mini-quadrupole paerture vs. the crossing angle problem. At 5 mrad angle crossing, the required $\underset{\sim}{\text { a }}$ perture becomes 42 mm PLUS the required beam size of 44 mm at $\beta=1.5 \mathrm{~m}$ and 38 mm at $\beta=2 \mathrm{~m}$. Thus the coil i.d. of these magnet should be 130 mm or larger. At 7 mrad crossing angle, the aperture requirement of QX 2 would be 160 mm coil i.d.. In the above calculation we have assumed,

$$
\begin{aligned}
& \mathrm{B}^{\prime}=56.0 \mathrm{~T} / \mathrm{m} \text { for Q1-Q4 with coil i.d. of } 130 \mathrm{~mm} . \\
& \mathrm{B}^{\prime}=66.7 \mathrm{~T} / \mathrm{m} \text { for other quadrupoles. }
\end{aligned}
$$

Therefore the length of QX2 may require even longer due to the obtainable gradient.

Table A. 2 MINI INSERTION lattice properties

|  | $\beta^{*}=2 \mathrm{~m}$ |  |  |  | $\beta^{*}=1.5 \mathrm{~m}$ |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| NAME | S | QX | BX | QY | BY | QX | BX- | QY | BY |
|  | -141.73 | 0.00 | 50.22 | 0.00 | 8.49 | 0.00 | 50.22 | 0.00 | 8.49 |
| "Q9I | -141.73 | 0.00 | 50.22 | 0.00 | 8.49 | 0.00 | 50.22 | 0.00 | 8.49 |
| Q9I | -141.30 | 0.00 | 49.46 | 0.01 | 8.65 | 0.00 | 49.45 | 0.01 | 8.65 |
| D891 | -120.88 | 0.16 | 12.21 | 0.15 | 77.48 | 0.16 | 12.08 | 0.15 | 77.63 |
| Q8I | -120.20 | 0.17 | 12.61 | 0.15 | 78.66 | 0.17 | 12.49 | 0.15 | 78.78 |
| "Q8I | -120.20 | 0.17 | 12.61 | 0.15 | 78.66 | 0.17 | 12.49 | 0.15 | 78.78 |
| Q8I | -119.52 | 0.17 | 14.08 | 0.16 | 74.03 | 0.18 | 13.97 | 0.16 | 74.08 |
| D78I | -114.15 | 0.21 | 37.16 | 0.17 | 27.64 | 0.21 | 37.21 | 0.17 | 27.17 |
| Q7I | -113.36 | 0.22 | 39.62 | 0.18 | 24.11 | 0.22 | 39.68 | 0.18 | 23.61 |
| "Q7I | -113.36 | 0.22 | 39.62 | 0.18 | 24.11 | 0.22 | 39.68 | 0.18 | 23.61 |
| Q7I | -112.56 | 0.22 | 37.97 | 0.18 | 23.33 | 0.22 | 37.98 | 0.18 | 22.79 |
| 1672 | -111.46 | 0.22 | 33.10 | 0.19 | 24.08 | 0.23 | 33.01 | 0.19 | 23.47 |
| BS2 | -102.01 | 0.32 | 7.84 | 0.24 | 35.19 | 0.33 | 7.48 | 0.25 | 33.96 |
| 1671 | -100.16 | 0.37 | 6.37 | 0.25 | 38.35 | 0.37 | 6.08 | 0.26 | 37.01 |
| Q6I | -99.58 | 0.38 | 6.36 | 0.26 | 38.09 | 0.39 | 6.12 | 0.26 | 36.59 |
| "Q6I | -99.58 | 0.38 | 6.36 | 0.26 | 38.09 | 0.39 | 6.12 | 0.26 | 36.59 |
| Q6I | -99.01 | 0.39 | 6.89 | 0.26 | 35.34 | 0.40 | 6.75 | 0.26 | 33.45 |
| I562 | -96.01 | 0.44 | 13.13 | 0.28 | 18.19 | 0.45 | 13.97 | 0.28 | 14.84 |
| BSII | -91.50 | 0.48 | 29.96 | 0.36 | 4.35 | 0.49 | 33.32 | 0.42 | 2.41 |
| 1561 | -89.24 | 0.49 | 41.77 | 0.47 | 2.83 | 0.49 | 46.87 | 0.57 | 3.25 |
| Q5I | -88.67 | 0.49 | 43.81 | 0.50 | 3.11 | 0.50 | 49.20 | 0.59 | 4.31 |
| "Q5I | -88.67 | 0.49 | 43.81 | 0.50 | 3.11 | 0.50 | 49.20 | 0.59 | 4.31 |
| Q5I | -88.11 | 0.50 | 43.40 | 0.53 | 3.80 | 0.50 | 48.69 | 0.61 | 5.98 |
| D45I | -81.47 | 0.53 | 27.13 | 0.63 | 34.18 | 0.53 | 29.38 | 0.67 | 61.47 |
| Q4I | -80.86 | 0.53 | 26.68 | 0.63 | 37.93 | 0.53 | 28.76 | 0.67 | 67.90 |
| "Q4I | -80.86 | 0.53 | 26.68 | 0.63 | 37.93 | 0.53 | 28.76 | 0.67 | 67.90 |
| Q4I | -80.25 | 0.53 | 27.74 | 0.63 | 39.74 | 0.53 | 29.81 | 0.67 | 70.72 |
| D34I | -35.48 | 0.60 | 397.63 | 0.73 | 164.06 | 0.60 | 397.42 | 0.73 | 177.66 |
| Q3I | -34.91 | 0.60 | 397.82 | 0.73 | 169.66 | 0.60 | 397.98 | 0.73 | 182.74 |
| "Q3I | -34.91 | 0.60 | 397.82 | 0.73 | 169.66 | 0.60 | 397.98 | 0.73 | 182.74 |
| Q3I | -34.34 | 0.60 | 383.22 | 0.73 | 181.91 | 0.60 | 384.67 | 0.73 | 194.47 |
| D23I | -28.38 | 0.61 | 189.08 | 0.73 | 386.63 | 0.60 | 203.20 | 0.74 | 388.68 |
| Q2I | -27.17 | 0.61 | 174.94 | 0.73 | 397.80 | 0.60 | 191.18 | 0.74 | 397.95 |
| "Q2I | -27.17 | 0.61 | 174.94 | 0.73 | 397.80 | 0.60 | 191.18 | 0.74 | 397.95 |
| Q2I | -25.96 | 0.61 | 196.13 | 0.73 | 334.78 | 0.61 | 216.37 | 0.74 | 335.70 |
| D12I | -24.50 | 0.61 | 247.79 | 0.73 | 231.02 | 0.61 | 274.92 | 0.74 | 233.80 |
| Q1I | -23.75 | 0.61 | 264.73 | 0.73 | 194.35 | 0.61 | 294.19 | 0.74 | 198.11 |
| "Q1I | -23.75 | 0.61 | 264.73 | 0.73 | 194.35 | 0.61 | 294.19 | 0.74 | 198.11 |
| Q1I | -23.00 | 0.61 | 257.84 | 0.73 | 177.52 | 0.61 | 286.47 | 0.74 | 182.78 |
| D013 | -22.00 | 0.61 | 233.46 | 0.74 | 166.73 | 0.61 | 258.97 | 0.74 | 174.36 |
| BC2I | -17.60 | 0.62 | 140.67 | 0.74 | 123.39 | 0.61 | 154.54 | 0.75 | 139.74 |
| D012 | -12.30 | 0.63 | 60.22 | 0.75 | 80.16 | 0.62 | 64.59 | 0.75 | 103.42 |
| BG1I | -9.00 | 0.64 | 27.44 | 0.76 | 58.17 | 0.63 | 28.40 | 0.76 | 83.74 |
| DX2 | -8.40 | 0.64 | 22.90 | 0.76 | 54.59 | 0.64 | 23.45 | 0.76 | 80.41 |
| QX2I | -7.09 | 0.65 | 16.95 | 0.76 | 40.73 | 0.65 | 17.73 | 0.76 | 60.31 |
| DX1 | -5.19 | 0.67 | 13.10 | 0.77 | 18.26 | 0.67 | 15.35 | 0.77 | 24.36 |
| QX1I | -3.60 | 0.70 | 8.50 | 0.80 | 8.50 | 0.68 | 10.15 | 0.79 | 10.15 |
| DX0 | 0.00 | 0.87 | 1.99 | 0.96 | 1.99 | 0.87 | 1.50 | 0.98 | 1.50 |
| "CR | 0.00 | 0.87 | 1.99 | 0.96 | 1.99 | 0.87 | 1.50 | 0.98 | 1.50 |


| "CR | 0.00 | 0.87 | 1.99 | 0.96 | 1.99 | 0.87 | 1.50 | 0.98 | . 50 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| DX0 | 3.60 | 1.04 | 8.50 | 1.13 | 8.50 | 1.06 | 10.15 | 1.16 | 10.15 |
| QX10 | 5.19 | 1.06 | 18.25 | 1.16 | 13.11 | 1.08 | 24.36 | 1.18 | 15.35 |
| DX1 | 7.09 | 1.07 | 40.72 | 1.18 | 16.96 | 1.08 | 60.31 | 1.20 | 17.72 |
| QX20 | 8.40 | 1.07 | 54.52 | 1.19 | 22.93 | 1.09 | 80.42 | 1.21 | 23.44 |
| DX2 | 9.00 | 1.07 | 58.06 | 1.19 | 27.49 | 1.09 | 83.72 | 1.21 | 28.39 |
| BC10 | 12.30 | 1.08 | 79.72 | 1.21 | 60.49 | 1.09 | 103.50 | 1.23 | 64.55 |
| D012 | 17.60 | 1.09 | 122.41 | 1.21 | 141.39 | 1.10 | 140.12 | 1.24 | 154.27 |
| BC20 | 22.00 | 1.10 | 165.21 | 1.22 | 234.68 | 1.10 | 175.07 | 1.24 | 258.36 |
| D013 | 23.00 | 1.10 | 175.87 | 1.22 | 259.17 | 1.11 | 183.59 | 1.24 | 285.75 |
| Q10 | 23.75 | 1.10 | 192.52 | 1.22 | 266.09 | 1.11 | 199.03 | 1.24 | 293.43 |
| "Q10 | 23.75 | 1.10 | 192.52 | 1.22 | 266.09 | 1.11 | 199.03 | 1.24 | 293.43 |
| Q10 | 24.50 | 1.10 | 228.81 | 1.22 | 249.07 | 1.11 | 234.91 | 1.24 | 274.21 |
| D120 | 25.96 | 1.10 | 331.50 | 1.22 | 197.15 | 1.11 | 337.34 | 1.24 | 215.81 |
| Q20 | 27.17 | 1.10 | 393.87 | 1.22 | 175.85 | 1.11 | 399.93 | 1.24 | 190.70 |
| "Q20 | 27.17 | 1.10 | 393.87 | 1.22 | 175.85 | 1.11 | 399.93 | 1.24 | 190.70 |
| Q20 | 28.38 | 1.10 | 382.83 | 1.22 | 190.02 | 1.11 | 390.63 | 1.24 | 202.70 |
| D230 | 34.34 | 1.10 | 180.30 | 1.23 | 384.85 | 1.11 | 195.52 | 1.25 | 383.80 |
| Q30 | 34.91 | 1.10 | 168.17 | 1.23 | 399.50 | 1.11 | 183.72 | 1.25 | 397.09 |
| "Q30 | 34.91 | 1.10 | 168.17 | 1.23 | 399.50 | 1.11 | 183.72 | 1.25 | 397.09 |
| Q30 | 35.48 | 1.10 | 162.63 | 1.23 | 399.31 | 1.11 | 178.63 | 1.25 | 396.55 |
| D340 | 80.25 | 1.20 | 39.97 | 1.30 | 28.03 | 1.18 | 71.17 | 1.31 | 30.08 |
| Q40 | 80.86 | 1.20 | 38.16 | 1.30 | 26.96 | 1.18 | 68.32 | 1.32 | 29.04 |
| "Q40 | 80.86 | 1.20 | 38.16 | 1.30 | 26.96 | 1.18 | 68.32 | 1.32 | 29.04 |
| Q40 | 81.47 | 1.20 | 34.39 | 1.30 | 27.43 | 1.18 | 61.84 | 1.32 | 29.68 |
| D450 | 88.09 | 1.30 | 3.82 | 1.33 | 44.04 | 1.24 | 6.02 | 1.35 | 49.34 |
| Q50 | 88.66 | 1.33 | 3.11 | 1.34 | 44.47 | 1.25 | 4.33 | 1.35 | 49.87 |
| "Q50 | 88.66 | 1.33 | 3.11 | 1.34 | 44.47 | 1.25 | 4.33 | 1.35 | 49.87 |
| Q50 | 89.22 | 1.36 | 2.83 | 1.34 | 42.40 | 1.28 | 3.26 | 1.35 | 47.51 |
| 0561. | 91.50 | 1.47 | 4.33 | 1.35 | 30.32 | 1.43 | 2.41 | 1.36 | 33.66 |
| BS10 | 96.01 | 1.56 | 18.21 | 1.38 | 13.24 | 1.57 | 14.93 | 1.39 | 14.04 |
| 0562 | 99.02 | 1.57 | 35.53 | 1.44 | 6.86 | 1.59 | 33.81 | 1.44 | 6.70 |
| Q60 | 99.60 | 1.58 | 38.30 | 1.45 | 6.31 | 1.59 | 36.98 | 1.46 | 6.05 |
| "Q60 | 99.60 | 1.58 | 38.30 | 1.45 | 6.31 | 1.59 | 36.98 | 1.46 | 6.05 |
| Q60 | 100.17 | 1.58 | 38.56 | 1.46 | 6.31 | 1.59 | 37.40 | 1.47 | 6.00 |
| 0671 | 102.05 | 1.59 | 35.34 | 1.51 | 7.76 | 1.60 | 34.27 | 1.52 | 7.38 |
| BS2 | 111.50 | 1.64 | 24.13 | 1.61 | 32.90 | 1.65 | 23.57 | 1.62 | 32.89 |
| 0672 | 112.62 | 1.65 | 23.36 | 1.61 | 37.84 | 1.66 | 22.86 | 1.63 | 37.94 |
| Q70 | 113.41 | 1.65 | 24.14 | 1.62 | 39.49 | 1.67 | 23.67 | 1.63 | 39.66 |
| "Q70 | 113.41 | 1.65 | 24.14 | 1.62 | 39.49 | 1.67 | 23.67 | 1.63 | 39.66 |
| Q70 | 114.20 | 1.66 | 27.68 | 1.62 | 37.03 | 1.67 | 27.23 | 1.64 | 37.20 |
| D780 | 119.57 | 1.68 | 74.15 | 1.66 | 14.04 | 1.69 | 74.10 | 1.67 | 14.02 |
| Q80 | 120.25 | 1.68 | 78.78 | 1.67 | 12.57 | 1.69 | 78.80 | 1.68 | 12.54 |
| "Q80 | 120.25 | 1.68 | 78.78 | 1.67 | 12.57 | 1.69 | 78.80 | 1.68 | 12.54 |
| Q80 | 120.93 | 1.68 | 77.60 | 1.67 | 12.17 | 1.69 | 77.64 | 1.69 | 12.14 |
| D890 | 141.35 | 1.82 | 8.62 | 1.83 | 49.62 | 1.84 | 8.62 | 1.85 | 49.62 |
| Q90 | 141.78 | 1.83 | 8.46 | 1.83 | 50.39 | 1.85 | 8.46 | 1.85 | 50.39 |
| "Q90 | 141.78 | 1.83 | 8.46 | 1.83 | 50.39 | 1.85 | 8.46 | 1.85 | 50.39 |


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