

Magnet Alignment for a Low Field Really Large Hadron Collider

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ABSTRACT

For the Really Large Hadron Collider (RLHC) there are proposals for low and high field designs. We discuss here the low field option. The number of magnet support points is very large. We consider time- and cost effective approaches to aligning the supports, and estimate the project costs to do so.

I. THE MASTER GEODESIC SYSTEM

We assume a tunnel diameter of 3 m. Muck removal will occur through vertical shafts of about 3 m diameter. We assume shafts every 3 km, spaced sometimes unevenly to suit surface features (e.g. to avoid populated areas).

Global Positioning System (GPS) receivers will be used on the surface to create monuments, which will be good to a few mm (6 mm for the SSC; the technology is improving). The monuments will be transferred to the tunnel via optical plumb and a length measurement (Invar chain, electronics). This transfer is good to a mm or so, if done carefully under good seeing conditions. In-tunnel monuments will be created as described below.

A. In-Tunnel Monuments

The tunnel will have 1 inch diameter stainless steel balls (welded to hex head zinc plated 10 mm steel bolts) mounted at mid height as pairs on both the inside and outside wall. The balls are placed at approximate locations, to be measured later. The balls occur every 30 m and are placed by low skilled tradesmen.

A total of 37,000 balls will be mounted. A team of two will do the job with a cart-mounted rock drill, and will set the balls into Hilti female sockets.

Total for 37,000 balls installed: 130 k\$

Each ball will have a bar-code identification. Crew travel times are not included, and may add 30% to total time on average.

B. Alignment Technology

The alignment job can be carried out by humans or by robots. The choice is based on whatever is less costly or otherwise advantageous. We examine here how humans would do the initial alignment, supported by significant automation.

All alignment will be based on the use of Lasertrackers, such as made by Leitz, Chesapeake, and others. These units consist of a servo controlled theodolite with digital axes readout into a computer. The theodolite emits a laser beam, which is reflected back from a portable retroreflector

mounted in a precision sphere. The operator holds a retro-reflector in his hand and places it in contact with the feature whose location needs to be determined. The theodolite reads out both axis angles and records the interference fringe count (up/down) since the last trigger. To initialize the fringe count, the operator places the reflector on all the monuments to be used to establish the system. The monument coordinates are known to the computer. The computer displays the best fit system and the errors assigned to each monument for approval by the operator. Newer instruments now appearing on the market can make absolute distance measurements. These devices are nearly accurate enough for this job today. They will make fully automated alignment considerably easier, because no direct mechanical contact with the monument balls will be needed. For now, we assume the use of existing lasertrackers.

One would place 8 balls near the GPS drop shaft to create a robust system. This system is propagated along the tunnel to the next drop shafts in both directions for closeout. It is also harmonized with the data from both drop shafts. The result is a best fit set of coordinates for each ball.

The equipment consists of the Lasertracker (on a tripod), the reflector, a small laptop computer with barcode reader and a radio communicator carried by the operator used to transmit bar codes and triggers, and to receive system results on a portable screen.

It is usually desirable to have two operators in the same area for safety reasons, but each operator would work independently, with their own system.

Time estimate for system establishment:

GPS data acquisition per shaft	3 hr.	crew of 2
Transfer to tunnel	6 hours	crew of 4
Number of shafts	167	
Total hours	5550 hours	2.8 myr

System propagation between two shafts:

Number of setups	100	0.5 hr/move
Number of balls measured/setup	8	0.5 h for 8 balls
Total for round-trip propagation	200 setups	200 hr.
Time for 167 shafts	37,000 hr.	18.5 myr

II. MAGNET ALIGNMENT

Magnets will be placed into stands that are pre-aligned to the required precision (assumed to be about 100 μ m) and pushed outward laterally to remove all backlash. Stands are

aligned before magnets are placed for the following reasons:

- no weight; adjustments are easier
- easier access to screws
- alignment can be done prior to, and independently of magnet delivery

A. Magnet Stand Alignment

Magnet stands occur every 5 m for a total of 110,000 stands.

If the spacing between stands can be increased to 10m, this will save 2.5M\$ in installation effort, and another 2.5 M\$ in stand costs.

Each stand will be aligned in three coordinates, height, roll, and radial position. The adjustments control two elevations and the radial position.

Stands will be placed using these steps:

1. Set up interferometer tripod halfway between two sets of ball monuments (0.3 hr for every 6 stands)
2. Create system by measuring 4 nearest balls (0.2 hr)
3. Use drill template and reflector to mark drill holes on the floor (0.2 hr)
4. Read required stand height from computer screen
5. Drill two holes, set two 10 mm female anchors (0.2 hr)
6. Select stand of proper height range and install (0.2 hr)
7. Mount magnet “phantom” on stand and align all three screws, using reflector (0.3 hr)

The steps above are sequential for each stand, but are “pipelined” between surveyor and installer. Total time is 0.6 hour surveyor time and 0.4 hours of installer time. Total time for all stands is

20,000 hr surveyor time	10 myr	1 M\$
20,000 hr installer time	10 myr	1 M\$

B. Guide Rail Alignment

The car guide rail provides the semi-precision reference for the magnet mover cars. The rail’s vertical and radial position will be measured along with the stand alignment described above. The extra time per stand location (to place the reflector and take a data point) is 5 min, for a total time of 9000 hours.

III. MAGNET STAND DESIGN

There will be 111,000 magnet stands. The stands must be cheap to make, robust, corrosion resistant, easy to install, easy to align, and be free of backlash and creep. It may be desirable to allow the possibility of robotic alignment for future upgrades.

One needs really two types of stands, the support stand and the anchor stand. Support stands are used every 5 m to hold up the long magnet. One anchor stand is used in the middle of each magnet to anchor its longitudinal position. Anchor stands are “few” in number (2111 for the 250m

long magnet) and simple. We will not discuss them any further.

Support stands are based on the use of threaded rods and backlash-free turnbuckles. Threaded rods are extremely stiff in axial direction and fairly flexible when forced sideways. We will use the latter property to allow the small amount of lateral motion needed to correct for drill hole location errors(± 3 mm or less) and to take up thermal expansion of the magnets (see below).

Fig. 1 shows such a stand. The stand mounts on the tunnel wall at about 0.9 m height. There is a base plate and a top cradle.

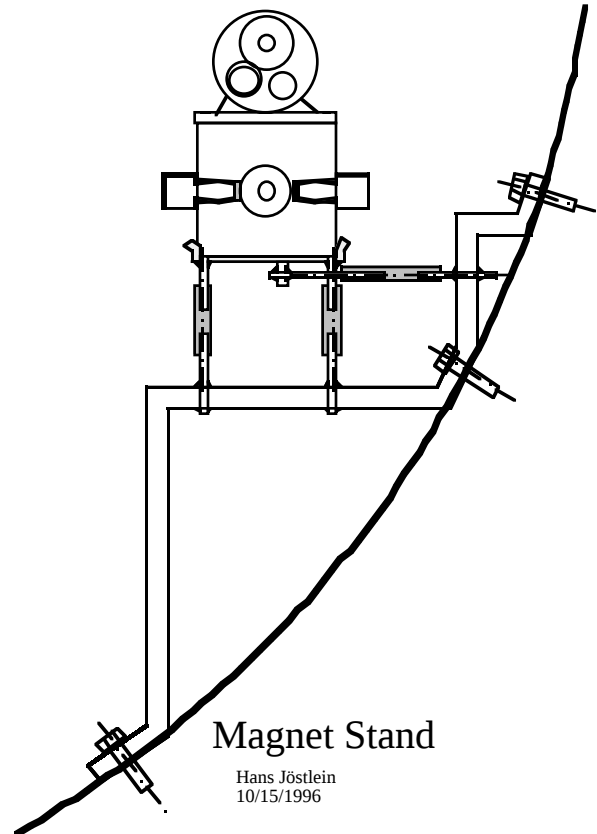


Fig. 1 Magnet Stand

The top cradle is a simple steel piece, about 25 mm by 25 mm in cross section, with the two prongs with lead-ins sticking up. The inner (i.e. toward the ring center) prong has a 6 mm set screw used to push the magnet outward and remove all backlash. The top cradle has two left-hand threaded rod pieces, 5/8” dia., welded on as shown. It also has a steel square with a 16 mm dia. right-handed threaded piece of rod welded to it.

The base plate is a piece of steel 50 mm wide x 20 mm high, bent as shown in Fig. 1. The base plate has two 16 mm diameter right-hand threaded rod pieces and another horizontal 12 mm diameter left hand threaded rod welded on as shown for horizontal control.

Three turnbuckles are used. All are backlash-free. The turnbuckles consist of a central hex pipe section with a left and a right handed internal thread. Two “die springs” are welded to it and to nuts as shown. An expansion tool is used when assembling the stand to create constant pre-load on each of the outer nuts. The vertical preload is used to assure good seating of the light-weight stand during alignment. The horizontal rod needs about 1500N of preload to avoid all backlash.

Note that each magnet will undergo a thermal expansion/contraction of about ± 7 mm for a 5 C temperature range. Stands are clamped to the magnet and all stands, except the anchor stand, will “sway” elastically to accommodate this motion.

IV. CONCLUSION

We have proposed ways of installing and aligning magnet stands.

Many of the techniques proposed here are amenable to further automation if that is cost effective. The total manpower identified for the magnet installation is under 100 man-years of largely low-to-medium skilled labor. Any potential manpower reduction appears not to support the engineering effort that would be required to automate such a complex operation, even with the large number of items involved.