ALIGNMENT OF DRIFT TUBE QUADRUPOLE LENSES USING A PULSED WIRE*

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Abstract

The Berkeley HILAC drift tube quadrupole magnet system has been aligned using a taut wire suspended along the accelerator axis. With a single magnet excited, the direction of movement of the wire, when carrying a pulse of current, indicates the position of one of the transverse magnetic planes with respect to the wire. Both planes can be aligned independently by reversing the direction of the current pulse in the wire.

The wire is vertically adjusted at its two ends to compensate for the calculated sag at each drift tube position. The adjustment of the mean (with regard to magnet imperfections and longitudinal skew) longitudinal axis of the quadrupole to the axis defined by the wire is extremely rapid, requiring about five minutes per drift tube, and deviations as small as 0.02 mm can easily be detected.

The precision of alignment of the HILAC system, limited by relatively coarse hanger adjustments and by thermal motion of the support system during alignment, is estimated to be $\Delta R < 0.1$ mm.

If a dc current is passed through a wire that is suspended parallel to the longitudinal magnetic axis of a quadrupole, the force on the wire will be toward one of the transverse magnetic planes (focusing) and away from the other (defocusing). For a wire under tension, suspended at points remote from, but free to move within, the lens, the motion will be predominantly in the defocusing direction, since the magnetic forces in this direction increase as the wire moves. If the dc current is sufficiently large, the wire is unstable in the defocusing, but stable in the focusing direction, and will come to rest at the magnet aperture extremity on the focusing transverse plane.

With respect to the defocusing plane, the wire will move either in a positive or negative direction, depending upon which side of the plane the wire was laying when the current was applied.

When the current ceases, the wire returns to its original position. If the current is reversed in direction, the roles of the focusing and defocusing planes are interchanged.

The position of the defocusing transverse magnetic plane with respect to the wire axis can thus be determined by observing the direction of motion of the wire when the current is applied. The magnet can be adjusted so that its defocusing plane lies very close to the wire axis by repeatedly moving the magnet in the direction of the wire movement; when the direction of the movement of the wire reverses, the transverse magnetic plane has crossed the wire axis.

The perpendicular transverse axis of the magnet can similarly be aligned to the wire axis by reversing the current in the wire.

The method provides no quantitative information of the position of the magnetic planes with respect to the wire axis, so that only the direction of the motion of the wire is of importance. The ultimate precision of the alignment of the magnet using this method, therefore, depends only on the distance the wire must have from the magnetic axis, in order that the direction of its motion be discernable.

The initial force on the wire is proportional to the strength of the lens, the displacement of the wire in its quiescent position from the magnet axis, and the wire current. The sensitivity thus increases with current. Unfortunately, for the fine wires that must be used, realizable dc currents do not provide adequate sensitivity for the technique to be useful. However, since only the direction of the motion of the wire is of importance, the current can be supplied as a fast pulse and, under these conditions the wire can tolerate extremely high currents. To distinguish the motion between the focusing and defocusing planes, it is necessary only that the current be sustained long enough so that significant movement of the wire occur during the pulse length. With the current pulse, the wire receives a local impulse away from the defocusing plane, and subsequently continues to vibrate. The direction of the initial motion of the wire under these conditions, however, is easy to detect, and the method is extremely sensitive.

In practice, it is difficult to determine the direction of the motion with respect to the defocusing, if the wire is remote from the focusing plane. The procedure of alignment therefore consists of the successive alignment of the two planes, with increasing sensitivity as the intersection of the two planes approach the wire axis. This description makes the procedure appear tedious and time consuming, but in reality the alignment can be accomplished quite rapidly. The adjustment of the magnets consumes the major portion of the time, since each wire measurement requires only a few seconds.

In applying this method of alignment to a linac drift tube system, two points at the ends of the cavity are chosen to define the accelerator axis and the wire is threaded through the drift tubes and adjusted to pass through the two points. Since the sensitivity of the determination of the drift tube position with respect to the wire is proportional to the distance of the individual magnets to the support points, the supports must be remote from the two end drift tubes. The wire lies exactly in the vertical plane defined by the two points, but sags symmetrically from the horizontal plane in a catenary.

The quadratic approximation of the catenary is satisfactory for this application, in that the total sag is less than 0.1% of the length of the span. The sag is described as

$$\Delta Y = \rho X^2/8W \tag{1}$$

where ρ is the mass/cm of the wire, X is the distance from the center of the span in centimeters, and W is the weight providing the wire tension, in grams.

The limit on the maximum allowable sag is defined by the radius of the smallest drift tube aperture; the SuperHILAC prestripper, with $X = 610$ cm and $R = 0.6$ cm, requires a wire with a very high ratio of tensile strength to density. An additional requirement on the wire is a relatively low resistivity, so that the required high current can be achieved with reasonable voltages.

For this application we have chosen 0.125 mm diameter tungsten (19 g/cm^3, tensile strength 34,000 gk/cm^2, and resistivity of 5.6 $\mu\Omega\cdot$cm). This wire is reliable with tensions of up to 70% of its calculated strength and, with this weight (3 kg), sags about 0.8 cm in a 35 m span.

This wire is, however, extremely vulnerable when subjected to sharp bends and must be handled carefully, to avoid breakage under the high tensions. The tie points at the support ends of the wire can be made by threading the wire through a fine 4 cm long copper capillary tube, swedging the tube along its entire length to capture the tungsten wire, and clamping the remote end of the tube to the supports. Sharp bends of the tungsten wire are thus avoided.

The drift tubes can be aligned to a straight line in the vertical plane by adjustment of the height of the wire supports to compensate for the sag at the position of each drift tube. In this compensation, errors in the estimation of the maximum sag of the wire will result in the alignment of the drift tubes to a contour that is parabolic in the vertical plane, with a maximum deviation from the desired axis equal to the error in the estimation of the sag. It should be noted, however, that of all possible alignment errors, this is the least objectionable.

To facilitate the adjustment of the wire to the desired accelerator axis, and to provide for the compensation of the sag, the wire is supported on two x-y tables, one of which has a 3 cm diameter ball-bearing guide wheel. The wire is secured firmly to one table, and passes over the guide wheel on the other to the tension weight. With each high current pulse, the wire elongates about 1 cm due to thermal expansion. To damp the oscillations of the weight, excited by this elongation, the weight is suspended in an oil dash-pot, attached to the x-y table.

The x-y tables are provided with dial indicators (0.01 mm per division, 12 mm travel) so that adjustments can be made without concern for screw backlash.

The maximum sag of several of these wires have been measured using a precisely aligned telescope under ideal conditions. These measurements are consistent, to within about 5%, with the sag calculated using the quadratic equation, with ρ determined from the measured total mass of a wire of 35 meter length. In these measurements, the telescope contributed the greatest error. The calculated sag was therefore used in the alignment of the system.

With the wire loaded to this high tension, none of the usual disturbing influences (bearing friction, thermal gradients along the wire path, air convection currents, etc.) affect the wire position to within the desired accuracy. When displaced, the wire returns to its quiescent position to within less than 0.01 mm.

For the lengths required, the wire has a resistance of about 100 Ω, the power supply consists of a capacitor adequate to provide time constants of several tens of milliseconds, charged to 500-600 V. The supply is connected to the ends of the wire (soldered to the copper capillary tube) and the capacitor discharged through the wire with a transistor switch. For our supply, we provided several capacitors and external resistors, so that the time constant could be varied to achieve maximum sensitivity. The optimum time constant varies, depending on how far the magnet being aligned is located from the wire support points.

For the alignment of the SuperHILAC, four men were required, one for each stem adjustment, one in the cavity to observe the wire and direct the movement of the drift tubes, and one to adjust the wire and height. Alignment requires about 5 minutes per drift tube, limited by the time necessary to move the drift tubes.

Only the magnet being aligned is excited, and residual magnetism in adjacent magnets does not appear to affect the precision of the alignment.

The strength of the quadrupole lenses in the SuperHILAC post-stripper cavity is 25 kg. With a time constant of approximately 20 msec, and peak currents of 5 A, the reversal of the direction of the motion of the wire were easily discernable for 0.02 mm movement of the magnets.

During the alignment, the cavities were maintained at a constant ($\pm 2^{\circ}$C) temperature, to restrict the thermal warpage of the system. Repeated checks of individual drift tubes indicate a positioning accuracy of about $\Delta R = 0.1$ mm.

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