Title

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Authors

Royet, J.M.
Scanlan, R.M.

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Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

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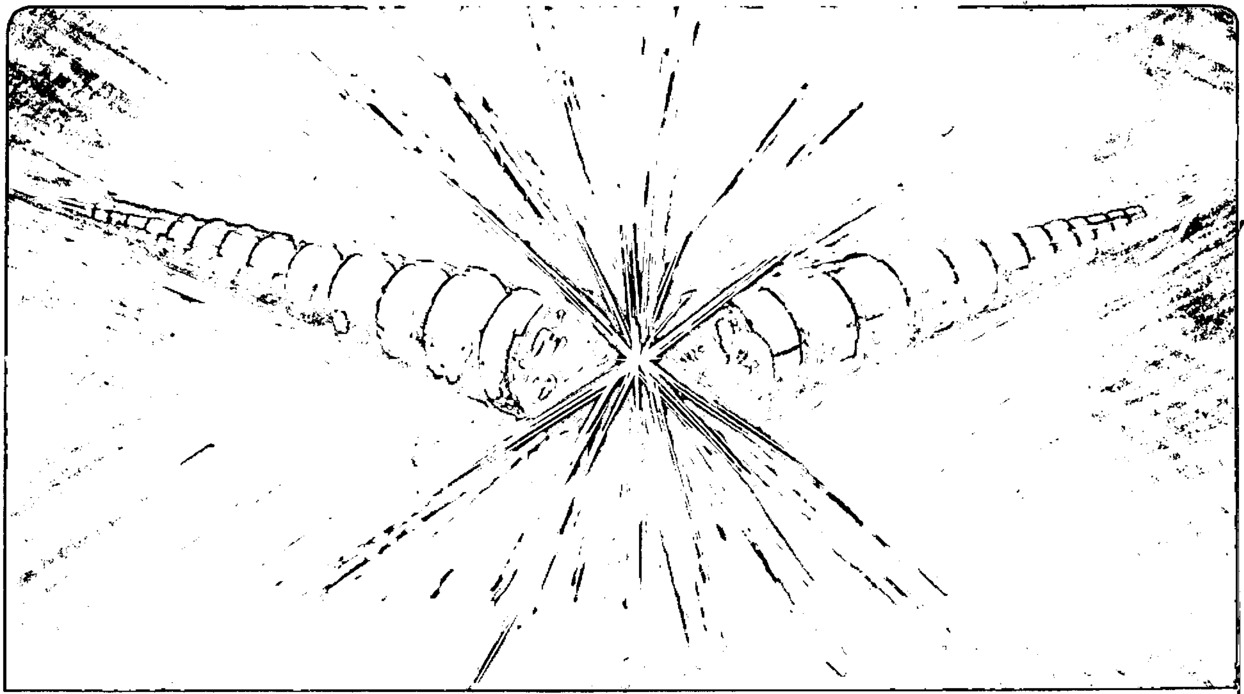

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J. Royet and R. M. Scanlan
Lawrence Berkeley Laboratory
University of California
Berkeley, California

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J. Royet and R.M. Scanlan
University of California, Lawrence Berkeley Laboratory,
Berkeley, CA 94720

***Abstract* — The cable is the heart of superconducting accelerator magnets. Since the initial development of the Rutherford cable, more than twenty years ago, many improvements in manufacturing techniques have increased the current carrying capacity. An experimental cabling machine was designed and constructed at LBL in 1984.**

I. INTRODUCTION

This machine was used to optimize the parameters for the SSC 40mm and 50mm bore dipole cables, as well as to manufacture the Fermilab low beta quadrupole cable. Improvements in manufacturing techniques, as well as in superconducting materials have increased the current carrying capacity. In addition to the cable optimization task, this machine was the only one of high quality available for early manufacturing of the SSC dipoles and quadrupole magnets and also for the Fermi Lab "low beta quadrupole cable"(3).

A. Mechanical Improvements

This machine originally made for 36 strand cables was upgraded to 48 and, more recently, to 60 strand capability. These successive enlargements were designed to determine the upper limit to the Rutherford type cables. The cable compaction is also a parameter to consider for the large cable's mechanical stability. This research is important for future economical magnet designs: one layer is cheaper than two [1] even if the superconducting material on the outer edge of the cable is not used at its best efficiency.

A new Turkshead was equipped with a dual power drive, mechanically independent, but with their torque motors connected in series so each side of the cable is pulled with the same torque to the rollers. The importance of a powered Turkshead is questionable for narrow Rutherford cables, say up to 36 strands; but beneficial for wider cables. This question was more extensively analyzed in the LBL publication " Magnet Cable Manufacturing " [2].

B. Additional Accessories

Our present Turkshead has the maximum flexibility that we can expect for manufacturing such cable. In addition we have installed a cable tension measuring device which allows adjustment of the linear capstan effort between 0 and 100%.

This strain gage based apparatus is useful to prevent a premature collapse of the wide cables (1). Interesting information obtained through this device is: the exact adjustment of the Turkshead position on the "Z" axis at the starting time of the cable when watching for the "pinch point" to occur. The linear capstan was also improved by introducing a differential gearing between the two main belt gears, allowing an equal and independent pulling force on each side of the cable.

C. Fiscal Year 92-93 Effort

During this period, the LBL cabling effort was focused on wide cable studies including the keystone aspect and the Nb_3Sn strands cabling. Another domain should be reported: the cabling of non-circular strands.

1) Wide cables: There are two ways to obtain wide cables: higher number of strands or larger strands for a given number of them. The higher strand number was already mentioned: 60 strand capability for the LBL machine. The larger strand size can result in other problems; e.g., a smaller cable number for a given magnet sector, then larger keystone angle needed. Also, flattening forces increase in the Turkshead which result in a deviation from the theoretical keystone angle given by the roller shape, due to the shaft flexion, adjusting screw compression, bearing play reduction, and frame extension. All those factors result in a difference between the micrometer reading of the cable mean thickness and the adjustment needed on the vernier governing the roller position. Obviously, the resulting cable is stiffer and the winding difficulties increased. This is more observable for NbTi wires. The Nb_3Sn is more difficult to characterize due to the various manufacturing processes. However, it is usually softer, and it is more sensitive to degradation. We have observed products which failed the "sharp bend test"; they show broken strands during cabling and a high degree of degradation critical current after reaction.

2) Flattened strands cabling: This program was motivated by three concerns:

—Make thinner cables with small or no keystone angle.

—Make pressure resistant reacted Nb_3Sn cables by increasing, the contact surface between the two wire layers of the cable, exposed to the high Lorentz forces under the magnetic field.

—Study the eventual cabling problems with conductors made of thin anisotropic filaments.

The first part of this program was implemented with NbTi wires, compacted at a two to one width over thickness ratio. We observed an important "memory release phenomenon" from the initial one twist per centimeter ratio. The final result was a tilted position of the strand over the mandrel

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which prevented fabrication of a correct cable. The results were better with a pre-twisting operation on the strand between the wire spool and the mandrel to cancel the memory release. The wire with anisotropic filaments is not yet available.

3) Other cabling machine improvements needed: Even on a sophisticated machine like the LBL cabler, some weaknesses appear during its operation: The useful length of the mandrel, theoretically governed by the dimensions of the cable needs fine tuning; this interaction between mandrel length and wire characteristics results in a phenomenon which is the amount of wire wrap over the closest end of the mandrel to the Turkshead before entering between the rollers. If the cable is already started, it is a risky operation to change this, in that the cable may collapse. A possible alternate method is to change the lay pitch of the cable. There is no risk in doing that, but the cable is slightly different after doing so in that the compaction is affected. The best solution, which we are working on, is to make the adjustment of the guide plate position on the "Z" axis. In other words, the angle of the wire versus the mandrel axis is adjustable without touching the wire already at the correct tension.

4) Cable optimization and manufacturability: Cable optimization is not a big problem when a close cooperation is possible from the beginning of the study with the magnet designer. Even with a very flexible machine such as ours at LBL, there is no continuous variation of all the cable parameters possible. From another point of view, for a large project in which all the cable parameters are settled, there is no need for a huge, complicated, and obviously expensive machine which will be more confusing for the industrial operator.

The concept of a very large machine equipped with heavy wire spools is also questionable: As far as the amount of wire in one load is sufficient to produce one layer of dipole magnet there is no need for more. Large spools are heavy and difficult to change. They also lead to a larger barrel diameter or more bays which result finally in a more expensive and slower machine. The reduction of the number of reloading operations is less attractive than the speed of production. In addition, we recommend that each machine be dedicated to one type of cable.

Acknowledgments

We wish to thank Rollin Armer for his contribution to the design and construction of the tension measuring device and differential gearing of linear capstan which are a great improvements on our cabling machine; Hugh Higley's expertise in the operation of our cabling machine is also to be recognized.

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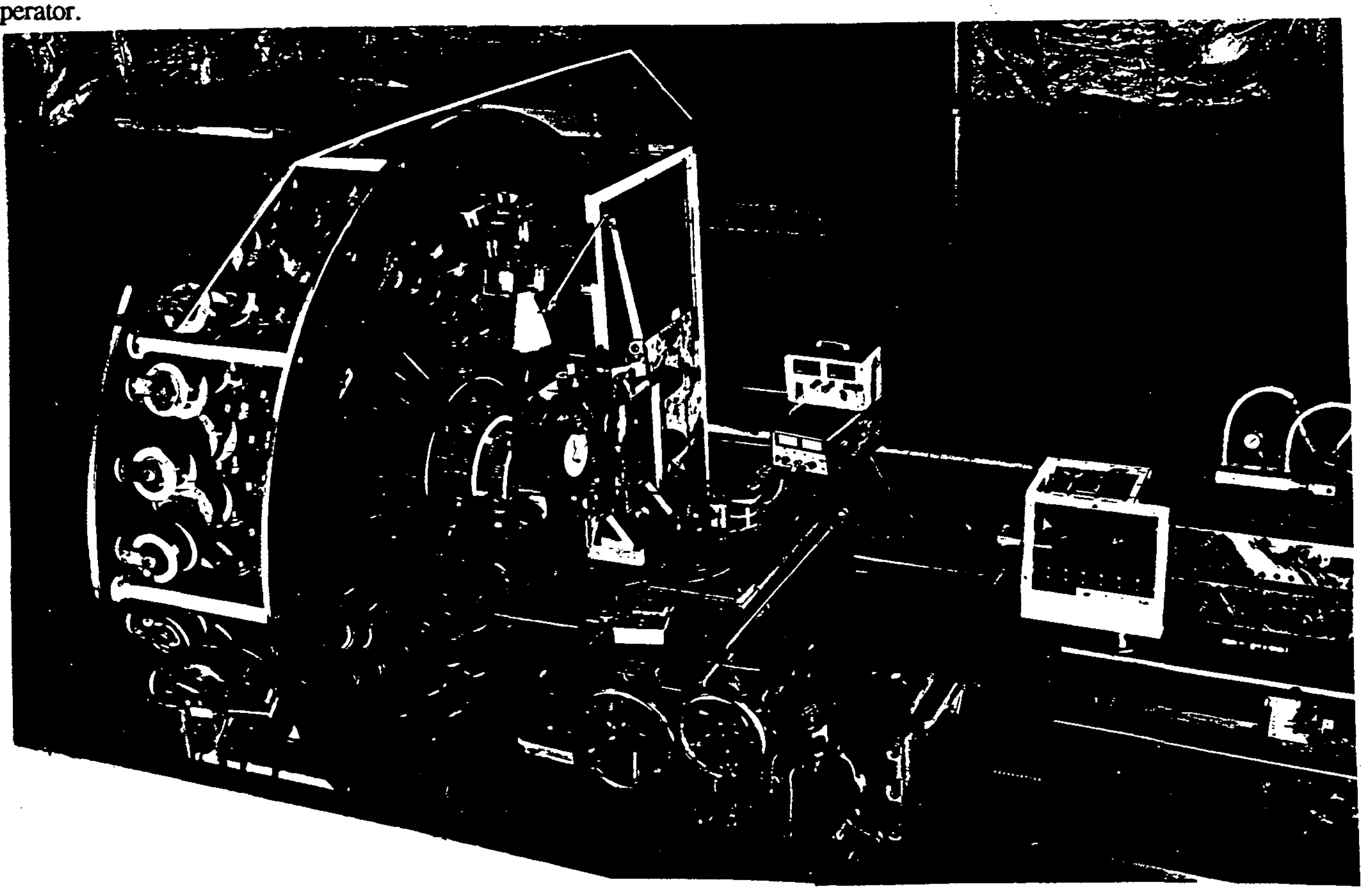

Fig. 1. Cable machine

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
TECHNICAL INFORMATION DEPARTMENT
BERKELEY, CALIFORNIA 94720