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PULSED MICRO-UNDULATOR FOR POLARIZED POSITRON PRODUCTION[1]

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Abstract. We represent here the elements of design and results of the testing for the helical undulator with ~2.5-mm period, manufactured in Cornell LEPP for polarized positron production at SLAC. At 2.3 kA undulator reaches K~0.2 and operated at 30 Hz.

INTRODUCTION

In our previous publications [1]-[4], we described some technical details of design for a short-period pulsed undulator. This undulator supposed to be used for experiment E-166 carried out at SLAC [5]. This experiment is dedicated to test the idea of polarized positron production for the ILC. This idea was proposed in [6] and its basis is that for generation of polarized positrons circularly polarized photons are used in the first place. These gammas, having energy ~10MeV converted into electron-positron pairs in a thin target. Secondary particles selected by energy as the particles with higher energy have higher degrees of longitudinal polarization. Circularly polarized photons can be radiated by high energy (~50 GeV in experiment E-166) primary electron beam passed through helical undulator.

Two types of undulators with parameters represented in Table 1 were fabricated. We also included parameters of SC undulator that is able to satisfy ILC needs for polarized positron production[2].

Table 1.

Energy, GeV	50	50	150
Length, m	1	1	100
Period, mm	2.52	2.43	10
Aperture dia, mm	0.889	1.067	8
Axis field, kG	~7.1	~5.4	~3.6
K	~0.17	~0.12	0.34
$\hbar w$, MeV	~9.15	~9.63	~19.3
Losses/part., J	2.6×10^{-13}	1.4×10^{-13}	6×10^{-11}
Losses, MeV	1.65	0.88	355
Quants/particle	0.18	0.09	~18
Current, kA-turns	2.3	2.3	8
Pulse duration, μs	12	13	¥
Heating/pulse ^{o}C	~1.7	~1.3	
Inductance@in μH	~1.4	~1.5	
Resistance, Ohm	~0.22	~0.26	SC
Inductive Voltage, V	~656	~592	
Pressure drop, psi	~11	~11	
Oil flow, gal/min	3.5	3.5	

[1] Electronic version is available at http://www.lns.cornell.edu/public/CBN/2005/CBN05-2/cbn05-2.pdf. This work supported by National Science Foundation.

[2] See details of SC undulator design in [13].

Finally these undulators were fabricated, tested and delivered to SLAC. As these undulators have unique characteristics among undulators, we will describe their properties, technology of fabrication and results of tests in a bit more detail.

GENERAL PICTURE

Basically, the undulator conductors are bi-helical windings with current running in opposing directions in these windings. This way of helical field generation was originated in [6]. Although some undulators were described in literature, [8]-[12], not one of these came close to the parameter list required. Finally we used here the way what we used successfully many years ago [13] for undulator, having period 6mm and *K*~0.35. We used the wires that have a rectangular cross-section, and they are giving ~15% higher field at the axis compared with the round wire, Fig. 1 and Fig.2.

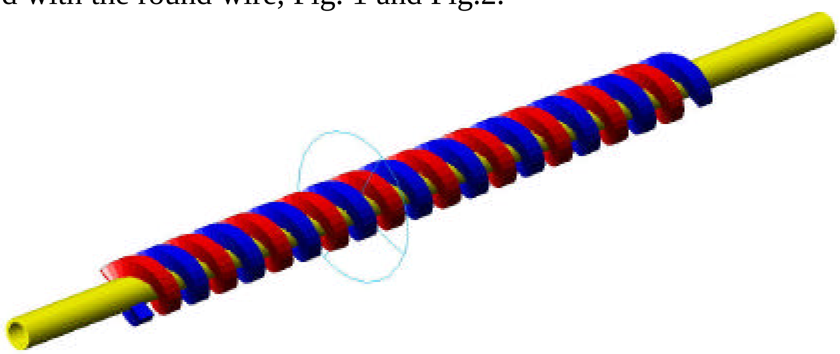

Figure 1: Core of undulator having right hand helicity.

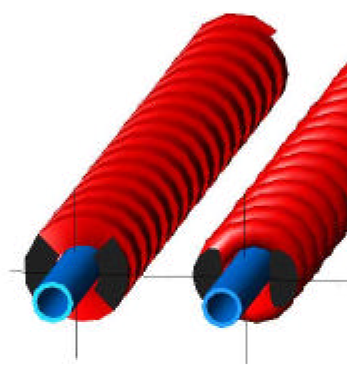

Figure 2: Rectangular wire, left and round wire cross section, right.

One can see from Fig.2, that the wire with the rectangular cross section has more conductor's material located closer to the axis and the path length for current is also shorter for the current with rectangular cross section as well. A wounding conductor with a rectangular cross section was found to be a problem of orders of magnitude more difficult, than wounding of wires with round cross section, however. Nevertheless, the result in field gain pays for itself. So the process for accurate wounding was developed. Also we suggested that an alignment of these windings could be done using *outer dimension* of winding as a reference. So these helical windings made directly to the (insulated) vacuum chamber. Further on this construction, rather flexible, aligned with the help of three cylinders. Kapton tape was used for electrical insulation here. Two of these cylinders are sitting in lower corners of U shape groove giving insulated lodgment for the whole helix.

So this U groove made with high accuracy at all length within ± 0.0005 inch margins. That was done in a few steps milling after all flanges with Al/StSteel transitions welded to the case. Two cases were milled at the same time attached to the Jig plate by holders as it will be in use. Cross section of the case is represented in Fig.3 and Fig. 4.

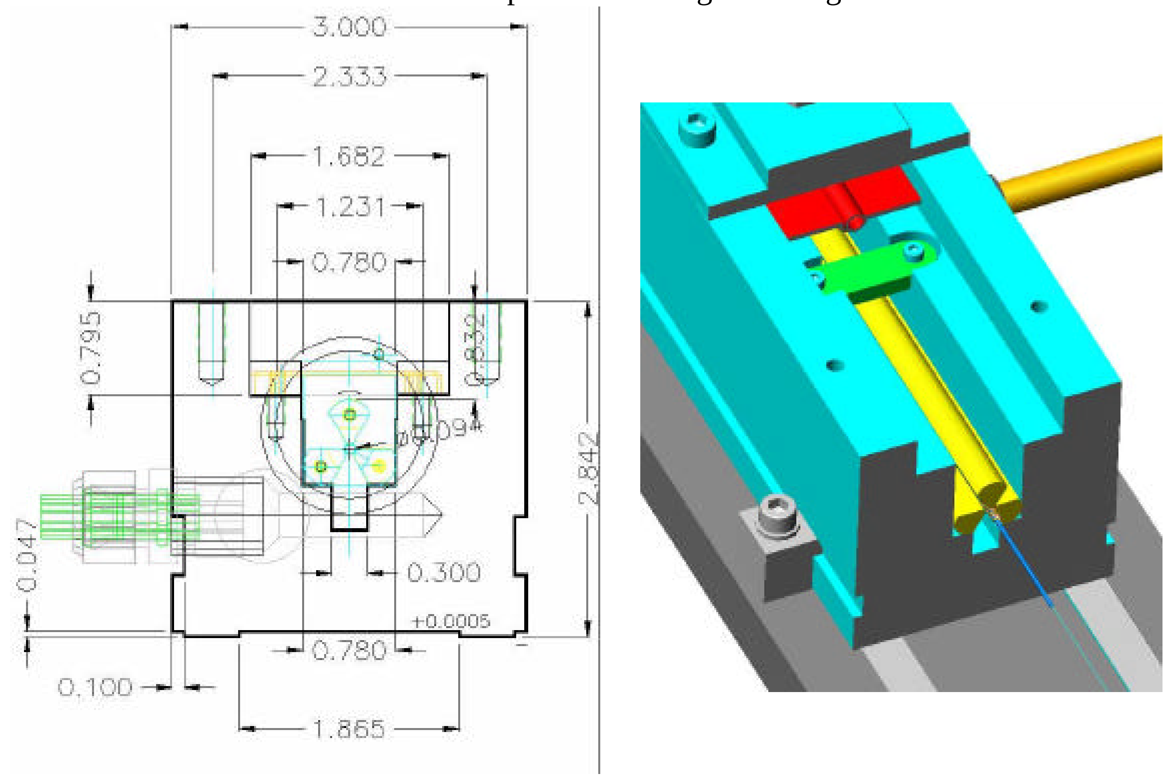

Figure 3: Cross–section in central region. Dimensions are at the left. Oil comes out through the tube connected to the space below G10 rods pained yellow.

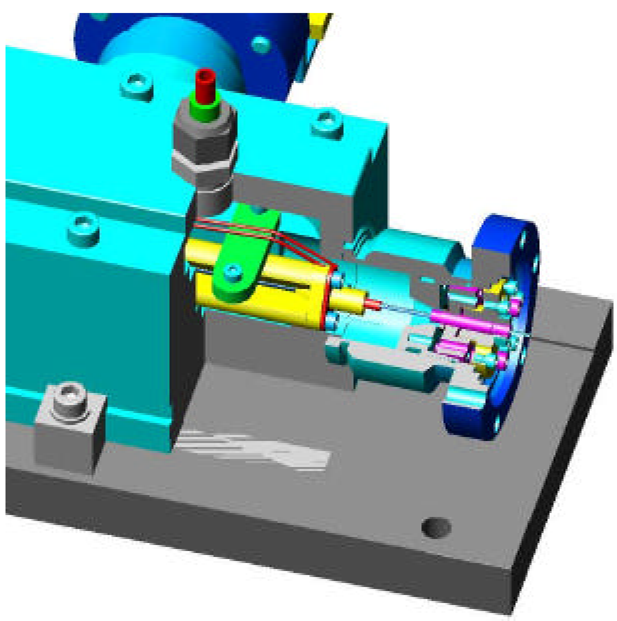

Figure 4: Cut trough the end of undulator. Specially designed flange allows 3D movements and angular adjustments.

G10 rods were found to be round with an accuracy within 0.05 mils at entire length. Upper cover, see Fig.3, Fig.4, sealing the inner volume with the help of Indium gasket.

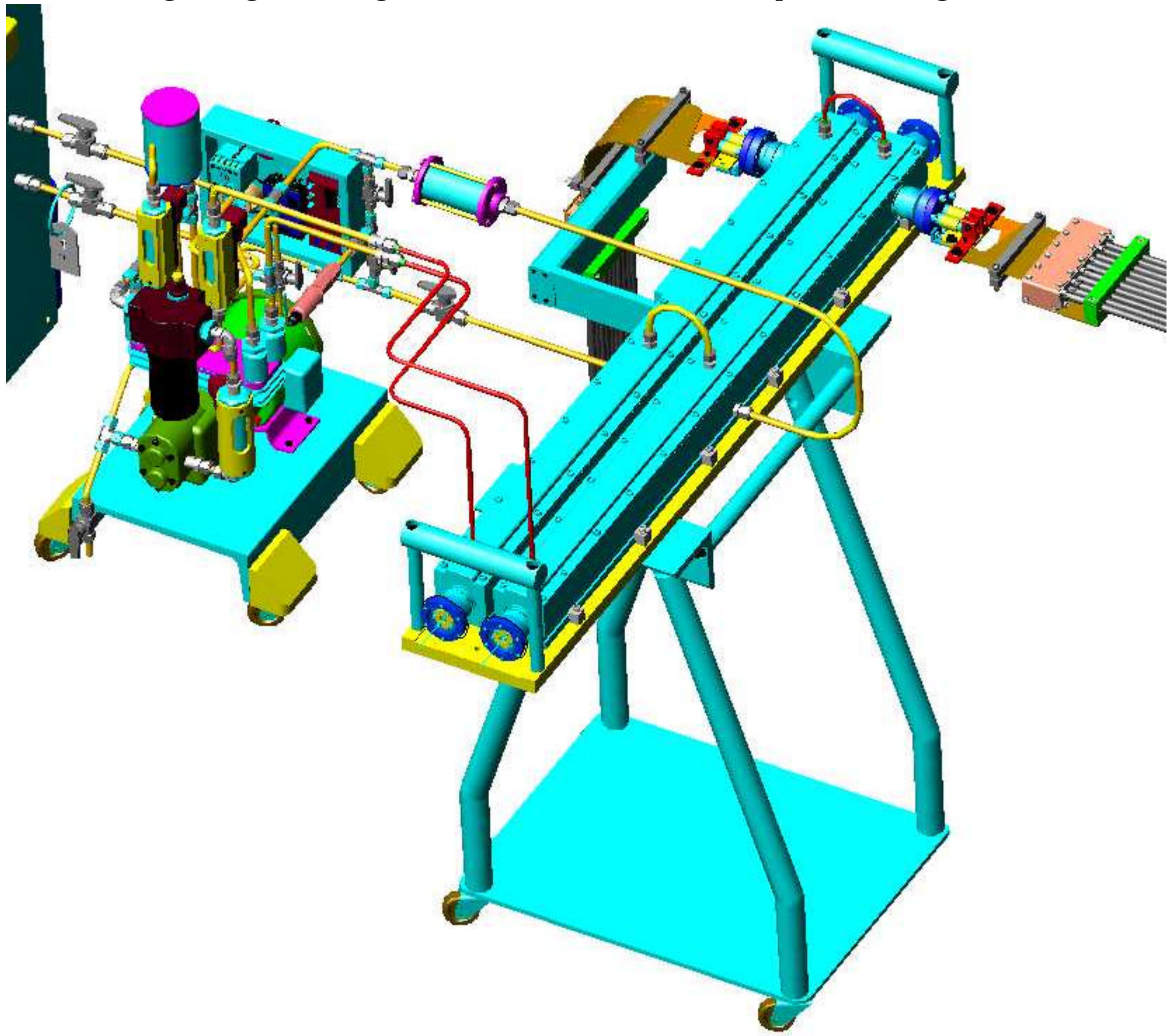

Figure 5: Set of two undulators installed on platform shown with cooling system, left. The last one shown with cover removed for better visibility.

Pure transformer oil used here as a coolant. Oil runs in a circuit that includes Stainless Steel oil pump, heat exchanger, reservoir, pressure gages and valves.

Heat is evacuated by two independent ways. First is running through water cooled heat exchanger. This heat exchanger made on Stainless Steel/Copper[3]. The second cooling loop settled as a heat exchange by water–cooled copper plate placed in upper part of undulator case, seen in Fig. 3 as painted red. This plate has width variation along the length so it also serves for proper distribution of oil flow along the undulator windings. Oil comes into the undulator case from the top in the middle and comes out at lowest point in the groove below G10 (See Fig.2) rods also in the middle. We also considered another loop for oil flow, so each case has four inlet holes. Internal pressure inside the case was found to be

[3] Alpha Laval model CB14-8.

~35 psi. Due to specifics in design, see Fig. 4, this pressure helps in stretching the chamber.

Pumping/cooling device is realized as a mobile unit, Fig.5, caring oil pump (made from StSteel), thermo-contacts loped in ready chain, flow meters, 3 phase control electronics, heat exchanger. This device can be turned on/off remotely as well as locally. Pressure transducer PS 302-200GV attached to the line through pressure snub PS-4E together with DP25-SR strain gauge meter[4], also attached to the ready chain loop. With the help of two valves the pressure transducer can be attached either to the out-going line or to the incoming one. The oil line is also equipped with standard dial-type pressure gages installed at the undulator side.

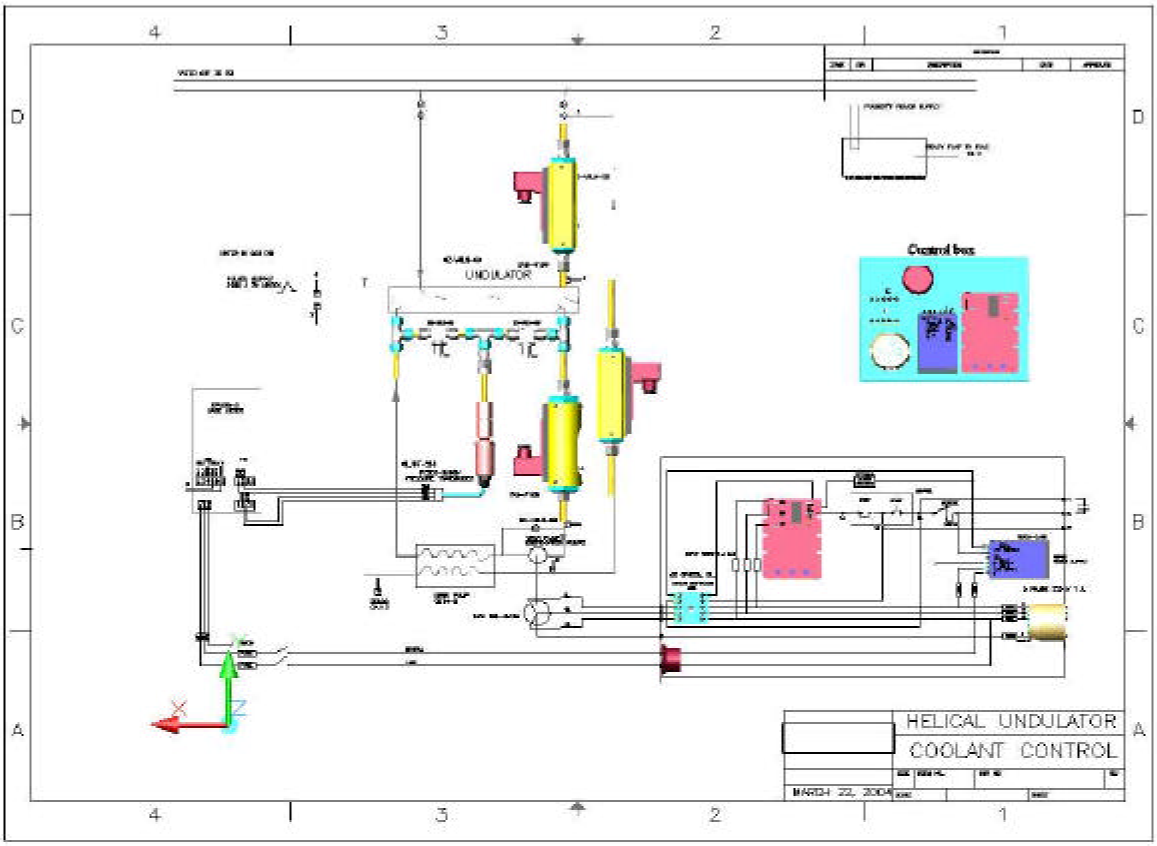

Figure 6: Ready chains for the undulator pulser.

All water flow meters have stainless steel parts only in contact with coolant. All the tubes, reservoir, valves, as well as the pump itself also made from StSteel. A meter also having Stainless steel parts in contact with oil used for measuring oil flow inside the cooling loop[5]. A Stainless steel high-pressure oil filter also has 20 μm stainless steel mesh.

At the second stage for cooling the Ferrofluid EMG-900 will be used as well [14]. Usage of Ferrofluid allows reaching a ~15-20% higher field. It will also make the pulse rise a bit slower, what helps in guaranteed operation of thyristors. So this will bring undulatority factor to the value $K \cong 0.2$.

[4] All from Omega Engineering Inc.
[5] KOBOLD Instruments model VKM-7208

FABRICATION

Oxygen-free CDA 10200 copper wire with square cross-section 0.6×0.6 mm^2 was ordered from company[6]. Corner radius is ≤ 0.06 mm. A specially designed machine was made for winding, Fig.7. Four wires were wound at a time: two of these are aforementioned copper conductors with rectangular cross–section and two additional wires used as spacers. After winding is finished, the last two wires are removed. Wounding is applied to the tube, wrapped by Kapton insulation directly. A hypodermic 304 L stainless steel small diameter tube 19-XTW with nominal OD 0.042 inch and inch and 18-XTW with nominal OD 0.050 inch and nominal wall thickness 0.004 were used for these purposes[7]. Kapton insulation, having a thickness of 0.5 mils, was used for insulation. After winding was finished, it was found that the windings were attached to the tube strongly enough and no sliding motion was found.

With spacer wire having 20 mils, period was found to be 2.58 mm as calculated, and with spacer 15 mils period comes to 2.29 mm. We used Copper wire having 19 mils in diameter as a spacer.

Before winding copper conductor was re-wound on Stainless Steel spools and annealed in vacuum.

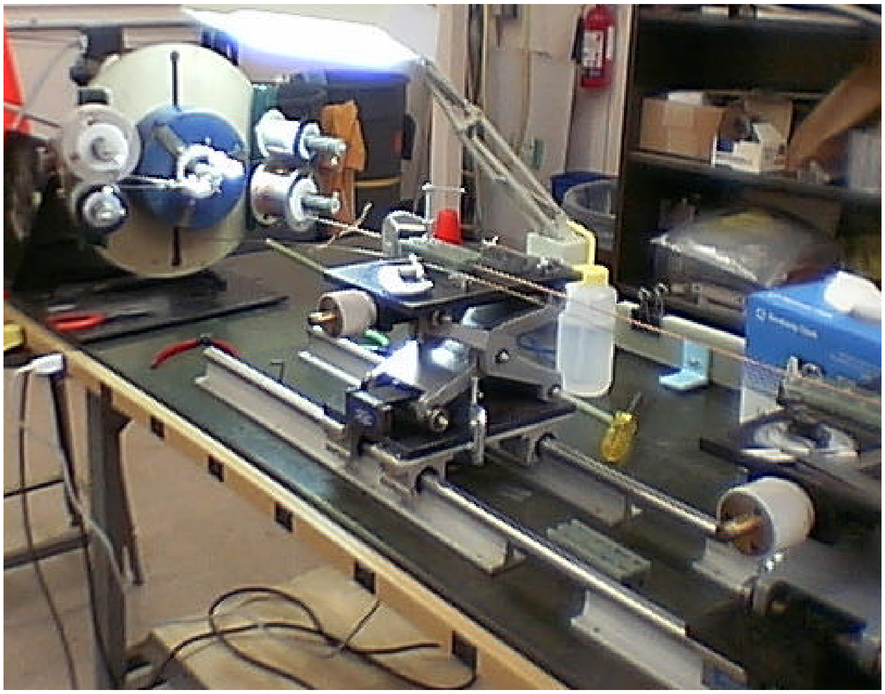

Figure 7: Winding machine.

The winding machine includes movable cartridges allowing adequate handling of the windings, which are rather flexible. These windings, sitting on the tube are rather strong in transverse direction, however, allowing compression to take place between the two rods.

All undulators wound as left-hand ones, i.e. having a twist opposite to an ordinary cork screw.

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[6] Accurate Wire Inc.

[7] New England Small Tube.

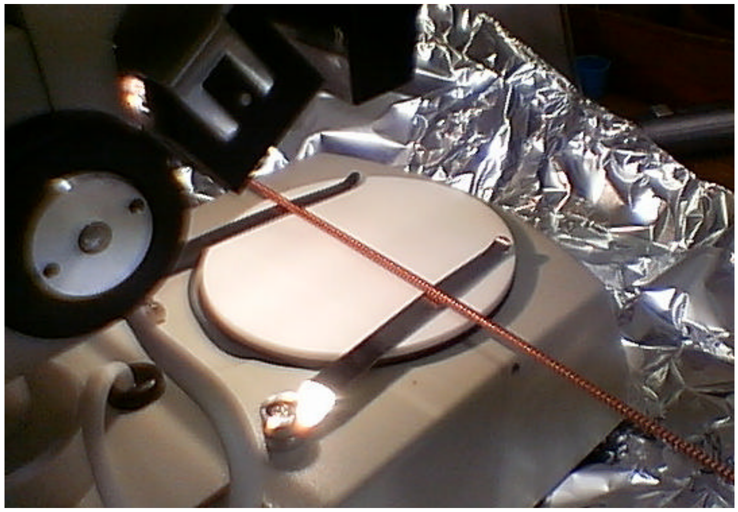

Figure 8: Each winding tested under a microscope.

Visual inspection under a microscope allows location of tiny pieces of copper chips inevitably deployed from the wire under the bend. Let just re-instate, that bending radius is of the order of the wire size. Keystone effect does not manifest itself much however and outer dimensions are rather uniform.

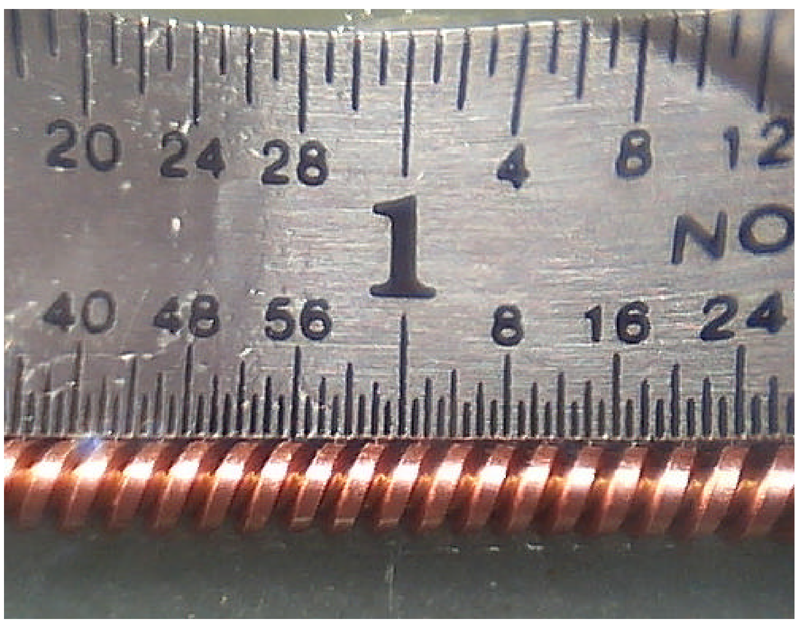

Figure 9: Windings enlarged. Scale in minimal division is 1/64 of an inch.

Inductance of each winding was measured also. It was easy to find any tiny metallic debris shortening the wires as the inductance change is going linearly with the length.
Special attention was paid to transferring the tube to the end cap. This end cap, seen in Fig. 10 at the right allows sealing the inner volume and allowing longitudinal motion, as the heat deposition yields some change in length. Soldering with hard alloy was found to be adequate to the task.

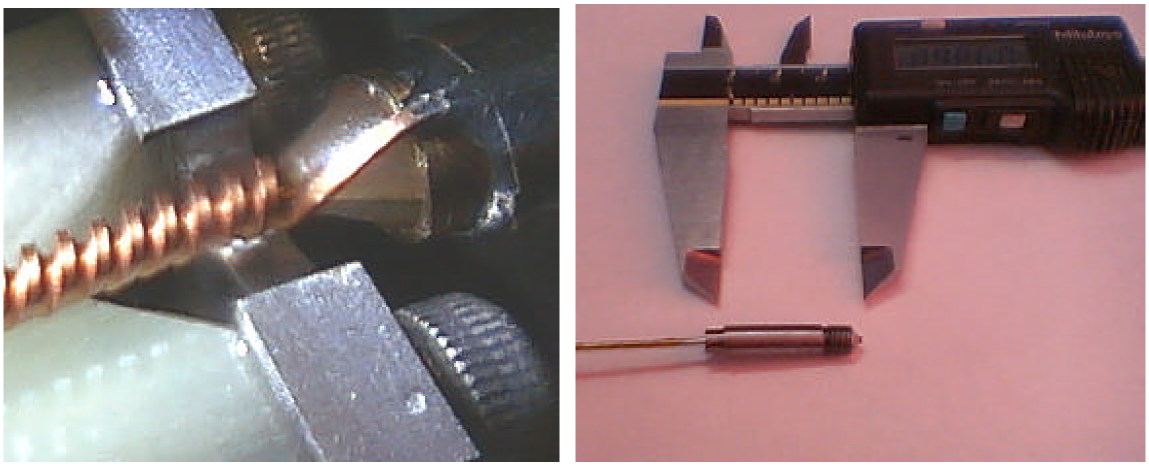

Figure 10: End jumper, left. End cap soldered to the tube, right. Caliper opened for 1 inch.

Another important factor defining the overall stability and precision is the case, holding G10 rods and helical windings, Fig.3. This case is made from Aluminum block having overall dimensions $\sim 3 \times 3 \times 45$ in^3. After preliminary milling was done, the flanges were welded. Stainless steel/Al transitions were used for these purposes. After that the final milling was accomplished. Dimensions were checked in local company with semi-automatic coordinate machine with touching head sensor, pretty standard device for high precision 3D measurements, Fig.11.

Figure 11: Test of dimensions with coordinate machine.

Aluminum Jig plate specially profiled and milled with high precision (better than ± 0.5 mils) accommodates two undulator cases. Attachment of each case to this plate made with special holders, allowing expansion in longitudinal direction. After fabrication, all Al parts oxidized black to minimized contact of Al surface with oil. This procedure does not change dimensions within controllable value.

ASSEMBLING

The assembly of windings in the case is pretty straightforward. It takes ~2 hours for reinstallation of new windings into case. Flanges allow transverse displacement of ends and angular motion together with the possibility for tube slide in longitudinal direction allow precise installation of helixes in place between two G10 cylinders, Fig. 12, left. After that the third rod is added, which attaches the windings down to these first two. For alignment we used visual look through the tube. Despite aperture being very small, it was possible to establish the procedure of traversing the helix on these rods. A flashlight pointed at the tube at one end with a reflector located out of the axis gives effective back light, so after some time it was possible even identify exact location of shift looking inside the tube. A laser pointer was also used for alignment, giving clear spot at opposite side of the wall in the assembly room. This laser spot was distinguished from the one produced by inner reflections. The design itself leaves very small room for improper installation, however.

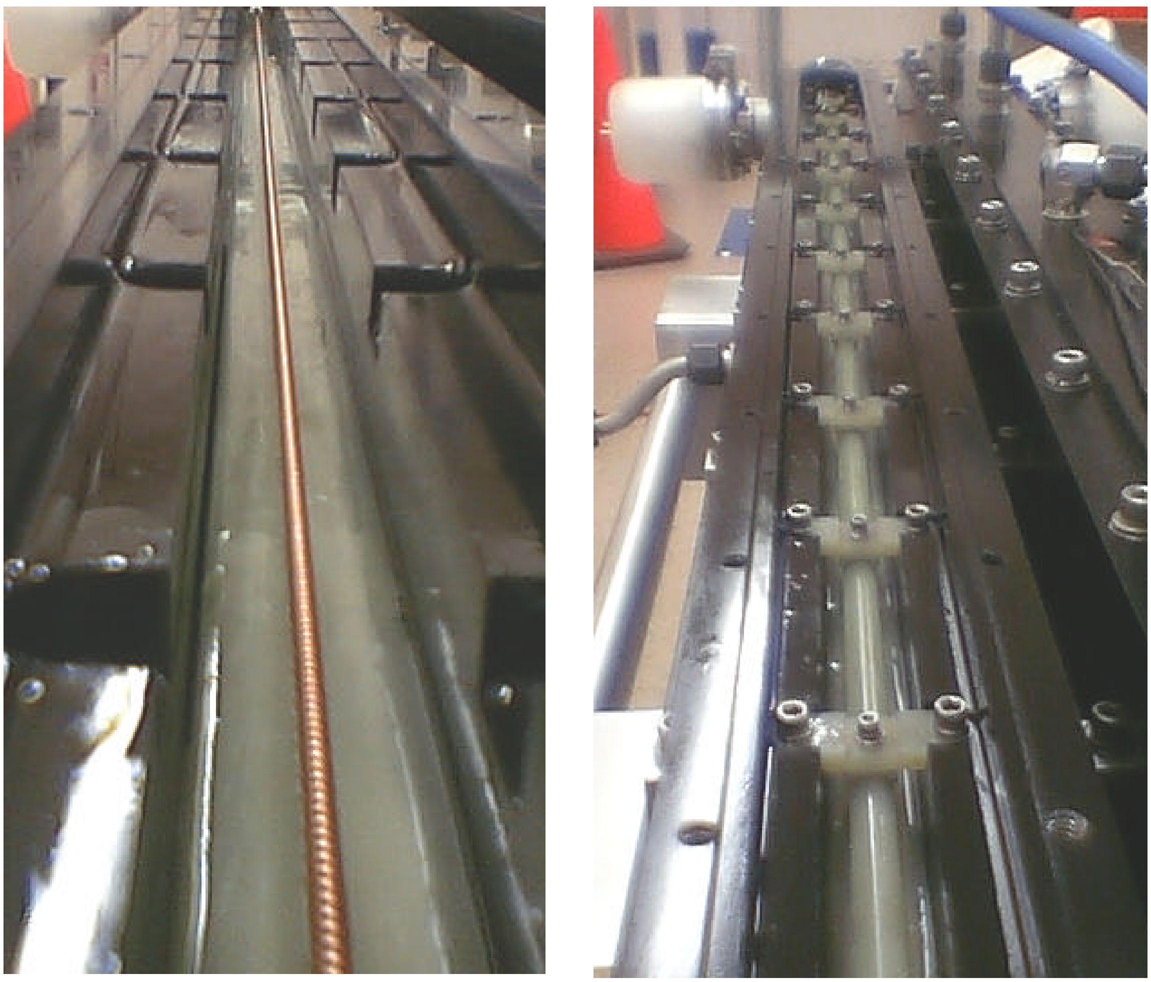

Figure 12: Windings located between G10 rods, left. At the right—the third road with help of transverse bars compresses these helical windings to the surface of these first two roads.

Feed-throughs for the current supply made from a standard pair of ceramic/copper transitions attached to the Stainless steel flange[8]. A transfer line running from pulser attached to the copper ends using flexible joints at the ends top avoids loading ceramics.

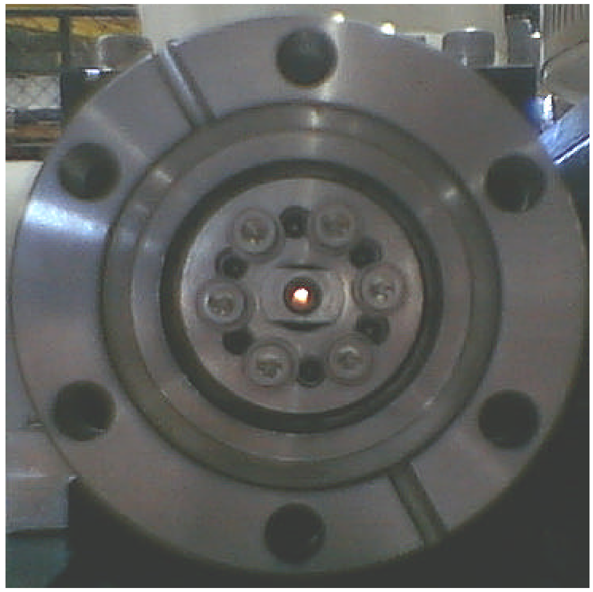

Figure 13: Light from flashlight coming from opposite side of undulator.

After the air is evacuated from the inner volume with the help of dedicated pump, oil is filled through funneled inlets visible in Fig.15, Fig. 16. Oil can be added in reservoir as well.

TESTING

Six full undulators were wound. Three for each tube: 42 and 50 mils in diameter. Each of these winding was tested in oil. Winding was immersed into plastic tube filled with oil and full voltage applied for few pulses. So in these tests there was no cooling, just heat capacity. For SLAC emittance $\gamma\varepsilon \cong 3\times 10^{-3}\, cm\cdot rad$ in a crossover of envelope function having value there $\beta_0 \cong 400 cm$ sigma of the beam goes to be $\sigma \cong \sqrt{(\gamma\varepsilon)\beta_0/\gamma} \cong 3.5\times 10^{-3} cm$. The stainless steel wire, having a diameter of 0.4 *mm* was stretched inside the aperture without touching the walls. The last was identified by absence of electrical contact between wire and tube. As 0.4 *mm* is ~ten sigma, then this is enough for successful beam pass through undulator. Further tests at SLAC after arrival there found that aperture is ~twice of this wire diameter we used in our measurements.
After oil pump is turned on, the oil pressure developed rather quickly up to 65 psi at the out of cooling system what opens the ready chain and allows pulsing.

Pulser is about the same as we used for positron production upgrade of CESR [15] and will be described separately. Further we are planning to use this power supply in CESR

[8] bought from Insulator Seal Inc.

conversion system as a spare unit. We also planning some tests after E-166 is finished, for the finding the limits of this device.

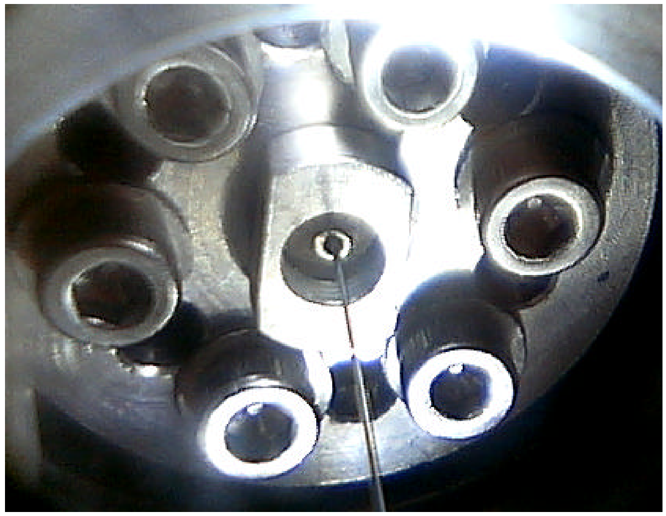

Figure 14: Aperture test. Wire of 0.4 mm in dia stretched trough the full length without touching the walls of inner tube having ~0.89 mm in diameter; magnified.

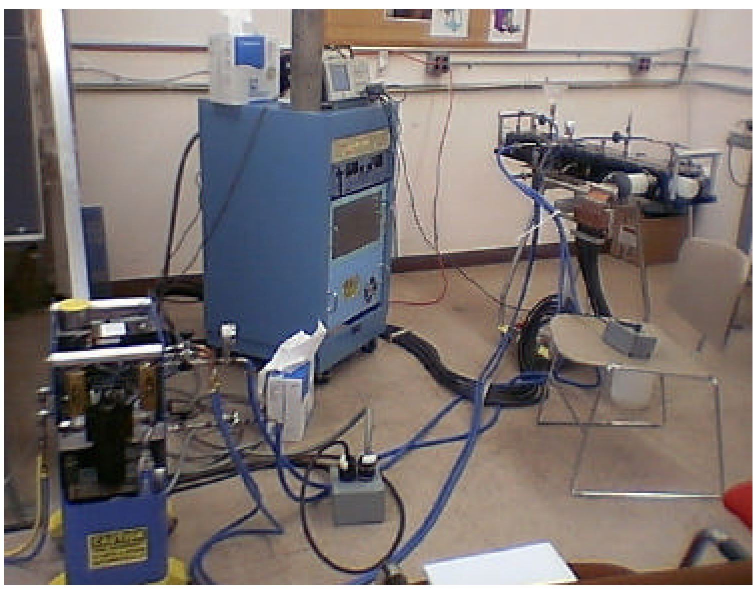

Figure 15: Photo of testing setup. Visible are undulators at the right, pulser at center and cooling system at the left.

We planned to measure magnetic field inside aperture, however the 3D Hall probe we received (having 0.4 ´ 0.4 ´ 15mm^3) has no wires attached to the crystal, so due to the time limits we did not accomplish this procedure, and are planning to do this in the future. We also fabricated Bi wire, having a diameter of 0.25 mm and a length of 1180 mm, insulated with enamel and inserted it into aperture. Then measurements at DC current up to 45 A was carried by measuring resistance change. This wire was calibrated in a known magnetic field. Again, results are not satisfactory as they show higher field as it can be expected from calculations (few times, even taking into account location of this wire inside aperture). This was explained by temperature change inside chamber while current is rising. Bi is known as extremely sensitive to temperature. We are planning to repeat these experiments in a future, however. So we will trust calculations, carried with help of *three different 3D codes.*

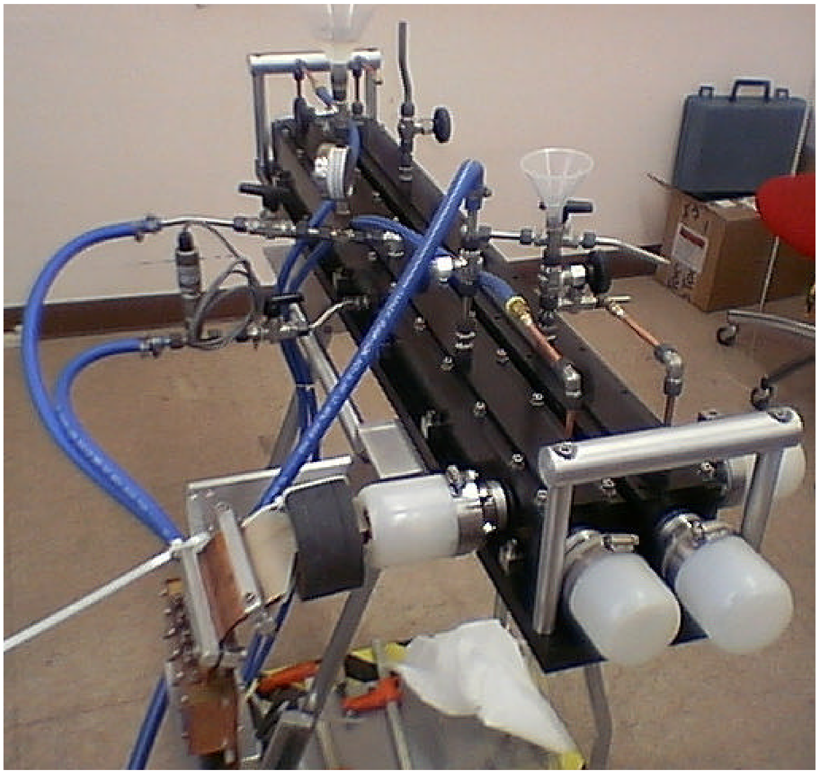

Figure 16: Wiggler under test. Plastic covers protect the flanges.

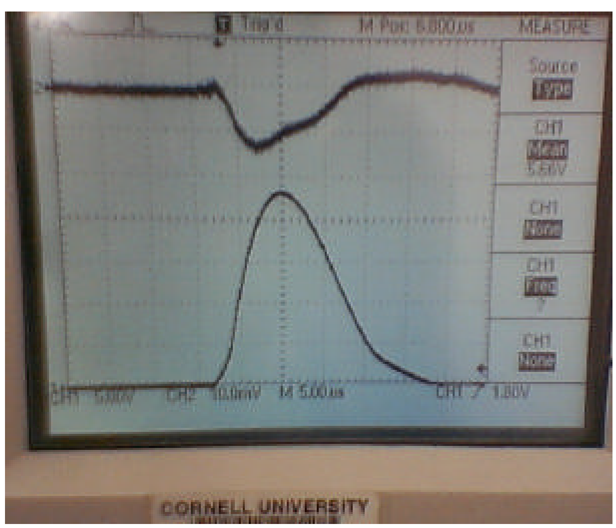

Figure 17: Pulsed current, low curve. Scales are 5 μsec/div for horizontal and 500 A/div vertical. Voltage drop at output of PS, upper curve. Full voltage ~600V. Undulator with 42-mils tube is under test here.

Undulator running at 2.3 kA was tested at 30 Hz during one our operation. This current developed with power supply EMS800-2.5-5-D at its high limit. This was done on purpose, so in case if all electronics failed, the power supply will be not able to develop extreme current. As all temperature relaxations occur in seconds, this time was found to be adequate. E-166 supposed to run at 10 Hz or even less, limited by radiation conditions.
After experiment at SLAC is finished it will be interesting to establish the limits, using other power supply.

CONCLUSIONS

This unique undulator was built in a very tight time frame (approximately six months from the beginning of calculations). Nevertheless all elements of design were found adequate to the task and remaining so.

This undulator, besides the test of polarized positron production experiment E-166 itself, can be used for arrangements of *polarized* electron-positron collisions in SLAC B-Factory, [16]. Four of these undulators required for successful operation (i.e. ~4 m total). For these purposes B-factory must be equipped by snakes for proper spin orientation. As all states in High Energy physics are polarized ones, this allow drastic reduction of background and at least will double the luminosity. As the ring is working at fixed energy there will be not a problem in arrangement of equilibrium spin trajectory in the ring.

In conclusion author thanks W.Trask, T.Moore, and K.Powers for theirs help in assembling of undulators and S.Chapman for his advices in testing of alignment. J.Barley and V.Medjidzade helped in pulser construction; pulser unit and cooling system will be described in detail in other place as they contain some non-trivial engineering solutions.

This job could only be finished thanks to support and attention of Maury Tigner, LEPP Director.

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