Geochemistry Geophysics Geosystems G3

Reply
Volume 11, Number 11
24 November 2010
Q11Y12, doi:10.1029/2010GC003295
ISSN: 1525-2027

Published by AGU and the Geochemical Society

Reply to comment by John Shaw on "A new high-precision furnace for paleomagnetic and paleointensity studies: Minimizing magnetic noise generated by heater currents inside traditional thermal demagnetizers"

Zhong Zheng
Geoscience Division, Sogokaihatsu Co., Ltd., Nishi-Koiwa 1-30-16, Edogawa-ku, Tokyo 133-0057, Japan (tei-cho@sogo-geo.co.jp)

Xixi Zhao
Institute of Geophysics and Planetary Physics, University of California, Santa Cruz, California 95064, USA (xzhao@uscs.edu)

Chorng-Shern Horng
Institute of Earth Sciences, Academia Sinica, PO Box 1-55, Nankang, Taipei 11529, Taiwan (cshorng@earth.sinica.edu.tw)

Components: 2700 words, 4 figures, 1 table.

Keywords: thermal demagnetizer; high-precision oven; paleomagnetism and paleointensity; magnetic noise field.

Index Terms: 1594 Geomagnetism and Paleomagnetism: Instruments and techniques; 1521 Geomagnetism and Paleomagnetism: Paleointensity; 1540 Geomagnetism and Paleomagnetism: Rock and mineral magnetism.

Received 13 July 2010; **Revised** 13 September 2010; **Accepted** 17 September 2010; **Published** 24 November 2010.

Zheng, Z., X. Zhao, and C.-S. Horng (2010), Reply to comment by John Shaw on "A new high-precision furnace for paleomagnetic and paleointensity studies: Minimizing magnetic noise generated by heater currents inside traditional thermal demagnetizers," *Geochem. Geophys. Geosyst.*, *11*, Q11Y12, doi:10.1029/2010GC003295.

Theme: Advances in Instrumentation for Paleomagnetism and Rock Magnetism
Guest Editors: M. Fuller, B. Goodman, J. Kirschvink, and K. Verosub

1. Introduction

[1] We thank John Shaw [*Shaw*, 2010] for pointing out that the magnetic noise generated along the axis of a standard MMTD80 thermal demagnetizer oven is much smaller than what we reported [*Zheng et al.*, 2010]. We agree with Shaw that we had erred in our original measurements for MMTD80 oven. Our new experiments have produced updated data (Table 1). We also note that the extremely low values of the two nonaxial components of the magnetic field in MMTD80 (RMS average X being 2.7 nT and RMS average Y being 1.7 nT) reported in Shaw's comments are much lower than theoretical values or known laboratory measurements. In addition, Shaw used a single-axis magnetometer for the measurement, which is well known to introduce large errors due to the uncertainty in sensor orientation. Thus, we have performed additional experiments using a triaxial magnetometer to examine this aspect. In order to provide a context for presenting the data acquired from these experiments, we also address the design considerations for high-quality thermal demagnetizers used in paleomagnetic research. For

Table 1. Comparison of Magnetic Fields Generated by Heater Currents in Our New Thermal Demagnetizer and Other Commercially Available Ovens[a]

	Sogo Fine-TD (nT)			Natsuhara, JP (nT)			ASCTD48, USA[c] (nT)			MMTD80, UK (nT)		
Current[b] (A)	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
0.00	8	7	14	7	−3	8	40	30	10	−1	14	−68
0.10	24	10	36				900	80	60	0	62	16
0.20	42	13	45				1700	190	40	3	115	80
0.30	64	16	63	820	270	510	2280	280	40	7	169	148
0.40	76	16	79	1060	360	640	2950	390	20	9	223	218
0.50	91	22	94	1310	460	790	3590	480	20	11	276	289
0.60	112	29	112	1540	550	910	4580	580	20	13	330	360
0.70	128	32	130				6230	730	150	14	384	434
0.80	146	35	143				7350	890	270	18	437	504
0.90	164	38	164							20	491	573
1.00	183	41	179							22	545	643
10	2.4 μT[d]			32 μT[d]			72 μT[d]			8.9 μT[d]		

[a]X, axial; Y, horizontal; Z, vertical.
[b]A direct current was applied to the heating elements. The generated field was measured near the central sample position by a triaxial fluxgate magnetometer. A corrigendum on the MMTD80 oven and an additional verification on the Sogo Fine-TD oven were performed, and the original data were updated.
[c]Between the three sets of heater elements of the ASCTD48, only the middle one (longest heater) was given electric currents.
[d]Extrapolated.

clarity, we will present our reply in the same structure as that in Shaw's comment.

2. Magnetic Noise Measurements

[2] Shaw is correct in stating that there are generally two types of noninductive heater windings used for thermal demagnetizer ovens at present, i.e., a single wire noninductively wound or a coiled single wire noninductively wound. We interpret here a coiled single wire to mean a solenoidal heating element. A solenoidal current is equivalent to the combination of an axial line current and a set of circular current loops. When the pitch between circular current loops is negligibly small and there is no flux leakage from the end of the solenoidal heating element, the magnetic field generated inside the solenoid is a uniform axially dominant field while the field outside is equivalent to that of an axial line current, a purely tangential field (i.e., field lines form closed circular loops), perpendicular to, and centered on, the line of current. The character of the magnetic noise field emanating from heater currents is quite different depending on methods of winding. Bifilar solenoid winding yields uniform axially dominant magnetic field in general, and when the pitch is shortened, the magnetic field can be canceled much more greatly and it becomes no longer axial component dominant [*Zheng et al.*, 2010]. Another winding method is the one used in MMTD80, in which heating elements are arranged in opposite directions along the axis of oven tube. In this case it is the number and arrangement of solenoidal heating elements that will govern the field strength and its distribution pattern. The field is no longer uniform, which is strongly dependent upon its distance from heating elements. The central axis of an oven is a special line where the field would become zero if the heating elements were arranged in the highest degree of symmetry. Hence we conclude that the field measured at the central axis is the representative value in the case of bifilar solenoid wound ovens. In the case of MMTD80 wound ovens, however, the field along the central axis would become a special one with the lowest value.

[3] Regarding the magnetic noise in the MMTD80 thermal demagnetizer, we carefully rechecked our experiments and found the field gradient calculated from the data of three different current strengths (0.10 A, 0.20 A, and 0.30 A) to be 190 nT/mA, which is consistent with the calibration factor of 170 nT/mA for a solenoid set in MMTD80. Furthermore, the ratio of axial over nonaxial component was higher than 33, which is a typical field of solenoid with a large number of coils per unit. It seems clear that in the previous measurements, the current was fed through the solenoidal coil designed for field generation for TRM experiments, rather than through the heating elements. The mistake was confirmed by our new experiment. We remark that various data sets reported in our original work [*Zheng et al.*, 2010] were acquired over time at more than one laboratory setting. We have ascertained

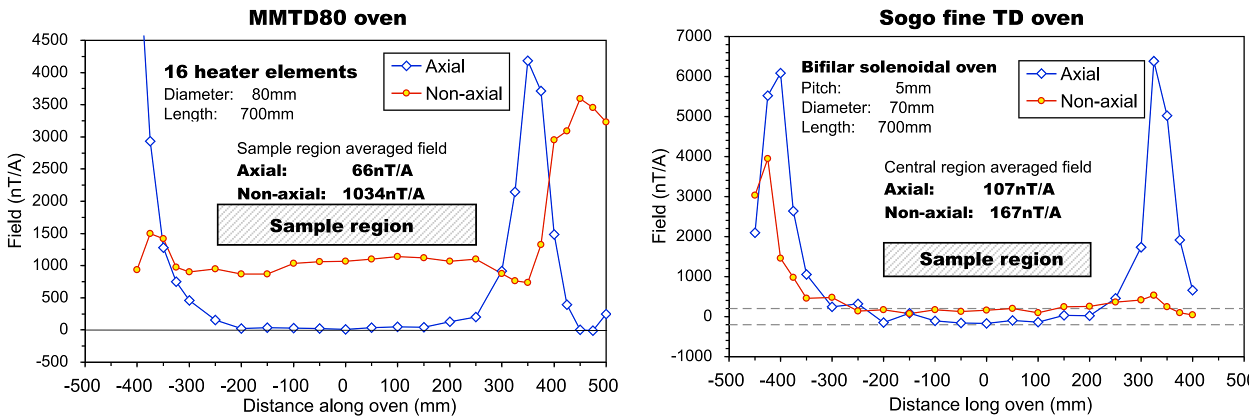

Figure 1. Graph of field along central axis of oven generated by passing direct current through the heater winding. (left) Data from MMTD80 oven and (right) data from a newly constructed Sogo Fine-TD oven. Nonaxial field component perpendicular to the oven axis is dominant inside the MMTD80 oven. In the sample region (hatched area) the field is low, with an average axial component value of 66 nT/A and nonaxial component value of 1034 nT/A (MMTD80), while the nonaxial field inside the Sogo Fine-TD oven is much weaker than that of MMTD80: in the sample region the average value of the axial component is 107 nT/A, and the average value of the nonaxial component is 167 nT/A.

that this was the only data set that was affected by the mistake. The data sets for Sogo Fine-TD, Natsuhara, and ASCTD48 were originally measured with a well-calibrated triaxial fluxgate magnetometer model 520. Our new experiments following Shaw's comments using the original setup, a model 520A of Applied Physics System, and a Bartington Mag 01 have confirmed the validity of the data. No experimental errors were found and the data and conclusions regarding these ovens by *Zheng et al.* [2010] remain correct and we stand by them.

[4] We carefully carried out a corrected experiment on the MMTD80 oven and acquired a new set of measurements on a newly constructed Sogo Fine-TD oven by using a well-calibrated triaxial fluxgate magnetometer model 520A and model 539 of Applied Physics System. The original Table 1 given by *Zheng et al.* [2010] has been corrected with updated data in this reply (Table 1). For comparison with Shaw's data, the measurements were also performed over the whole central axes of the ovens. Figure 1 shows the results of the MMTD80 oven in comparison with the data from the Sogo Fine-TD oven. The averaged axial component during the sample region is similar to that of Shaw's data (66 nT/A versus 48 nT/A); however, a great discrepancy is found in the nonaxial direction (1034 nT/A versus less than 6 nT/A reported by *Shaw* [2010]). As we stated earlier, the field in the MMTD80-type oven is nonaxially dominant, and Shaw's measurements on the nonaxial direction using a single axial magnetometer do not appear to be reproducible and are inconsistent with our repeated measurements using a well-calibrated triaxial fluxgate magnetometer.

3. Aspects of MMTD80-Type Oven

[5] As we stated in section 2, the bifilar solenoid wound oven yields uniform axially dominant magnetic field in general, while in the case of the MMTD80-type wound oven, the field distributes inhomogeneously in space, and its strength and spatial pattern are strongly controlled by the number and arrangement of solenoidal heating elements. To clarify these important aspects, we have carried out further experiments on a proxy of MMTD80-type wound oven. Because the field generated outside by a solenoidal current is almost equivalent to that of an axial line current, it is reasonable to use a single enameled copper wire as a proxy of solenoidal heating element in following experiments. Following the winding method used in MMTD80, a few heating elements were arranged on the surface of a tube in opposite directions along its axis as symmetrically as possible.

[6] Figure 2 shows the field measured along the central axis of the tube with the number of heating elements varying from 4 to 32. The diameter of the tube is 65 mm, which is slightly smaller than the 80 mm diameter of MMTD80. All the ovens yield nonaxial dominant fields, and in the case of 16 heating elements, which is the same number as the MMTD80, two sets of data are remarkably consis-

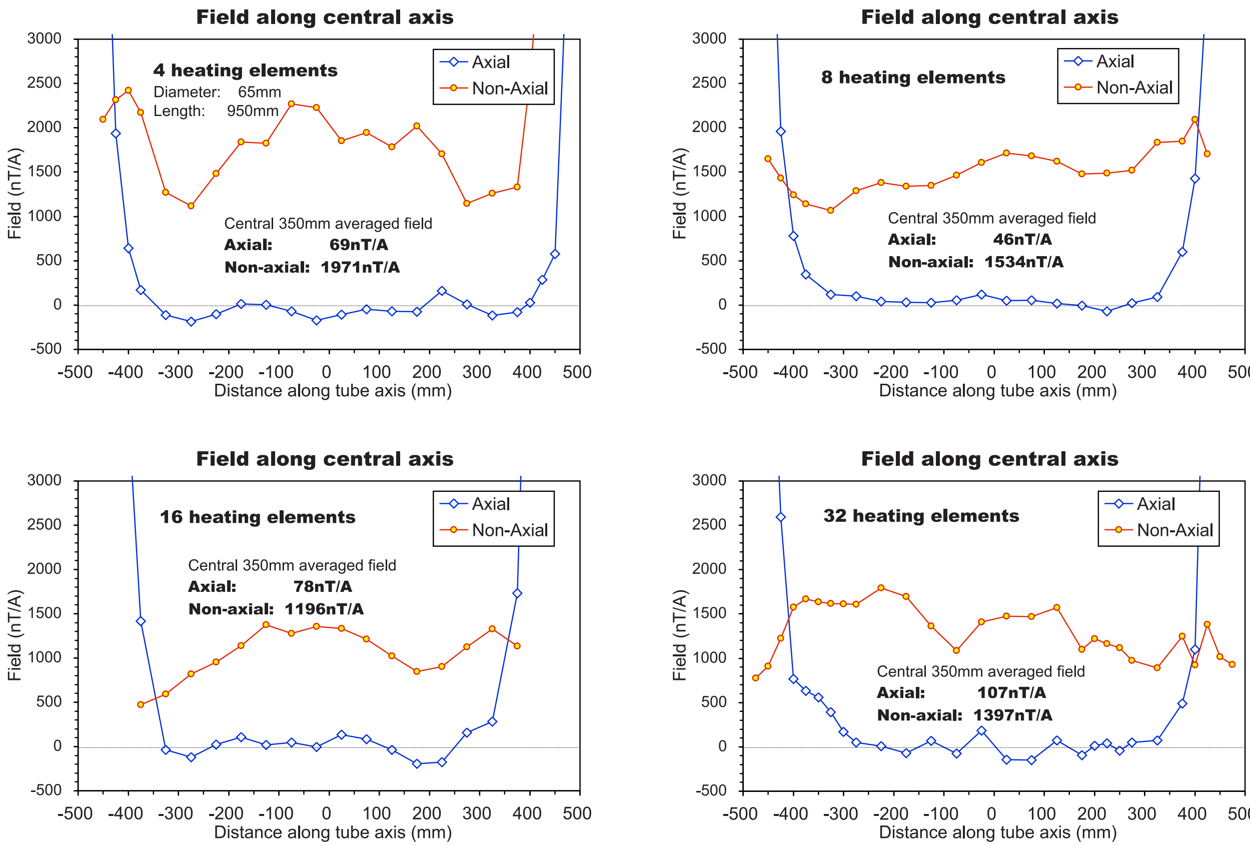

Figure 2. Graph of heater current produced field along central axis of MMTD80-type oven with the number of heating elements varying from 4 to 32. All the heating elements are symmetrically arranged on a tube surface in opposite directions along the axial direction of the tube. Single enameled copper wire was used as a proxy of solenoidal heating element. The diameter of the tube was 65 mm, which is slightly smaller than the 80 mm diameter of MMTD80. The distribution of the field along the central axis is remarkably consistent with that of MMTD80, and dominant non-axial fields were confirmed again. For an oven with a large number of heating elements (greater than 16), the high degree of symmetry of the heating element arrangement acts more effectively to reduce the field along the central axis.

tent: in the central region the averaged axial component was observed to be 78 nT/A versus 66 nT/A for MMTD80, and the dominant nonaxial component was 1196 nT/A versus 1034 nT/A for MMTD80. When the number of heating elements was increased from 4 to 16, better cancellation was achieved and the strength of the nonaxial field decreased from 1971 nT/A to 1196 nT/A. However, when the number was further increased to 32, no significant improvement was observed: the nonaxial field still remained at a high value of 1397 nT/A. It is clear that the high degree of symmetry of the heating element arrangement acted more effectively to reduce the field along the central axis.

[7] Because of the large dimension (greater than 30 mm) of the triaxial fluxgate magnetometer, it is difficult to measure the field aspects in the radial direction for a normal size oven (diameter less than 80 mm). We thus constructed a special large-diameter (215 mm) “oven” to clarify the radial aspect of the field. The data obtained both along the radial direction in the central position and along the central axis of the “oven” are summarized in Figure 3. Again, it is confirmed that the field along the central axis is of the lowest strength, and the improvement is strongly dependent upon the degree of symmetry of arrangement of heating elements rather than its number. The field with eight heating elements was found to be the lowest. However, the low-field region was found to be strongly controlled by the number of heating elements: it is only 10% in the central area when the number is 4, and it stretches to 30% when the number is 8 and 50% when the number is 16 (Figure 3, top).

[8] For comparison, the field along the radial direction was also measured for a bifilar solenoid wound oven. The same large-diameter (215 mm) “oven” has been constructed with the coil number

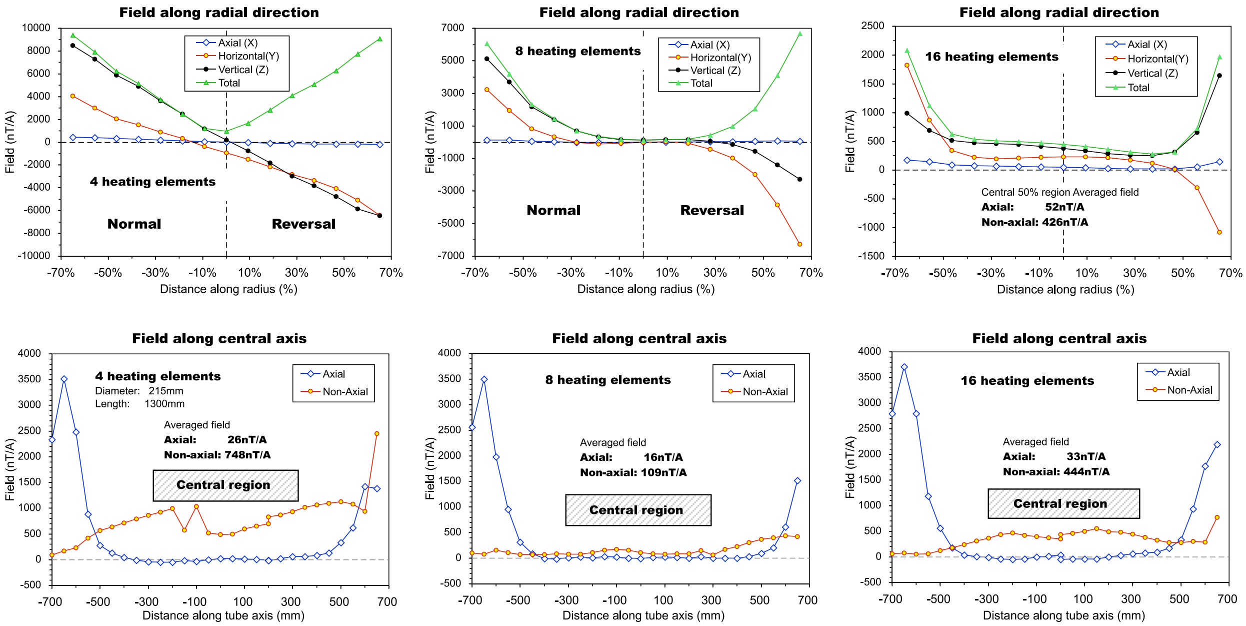

Figure 3. Uneven distribution of heater current produced field in MMTD80-type oven with large diameter (215 mm). (top) The distribution of the field along the radial direction and (bottom) the field along the central axis. Single enameled copper wire was used as a proxy of solenoidal heating element. The low-field region is strongly controlled by the number of heating elements. It is only 10% in the central area when the number is 4, and it stretches to 30% when the number is 8 and 50% when the number is 16.

14 per diameter unit, the same as that of the Sogo Fine-TD oven. The pitch for the former is 15 mm and for the latter is 5 mm with diameter of 70 mm. The field inside the solenoidal current is almost uniformly axis dominant and its strength simply depends on the number of coils per diameter unit. As expected, a very low homogeneous field (less than 300 nT) was observed in the entire measurable region (70% of radius (Figure 4, right)).

4. Conclusion

[9] The data for the MMTD80 oven reported by *Zheng et al.* [2010] contain serious mistakes caused

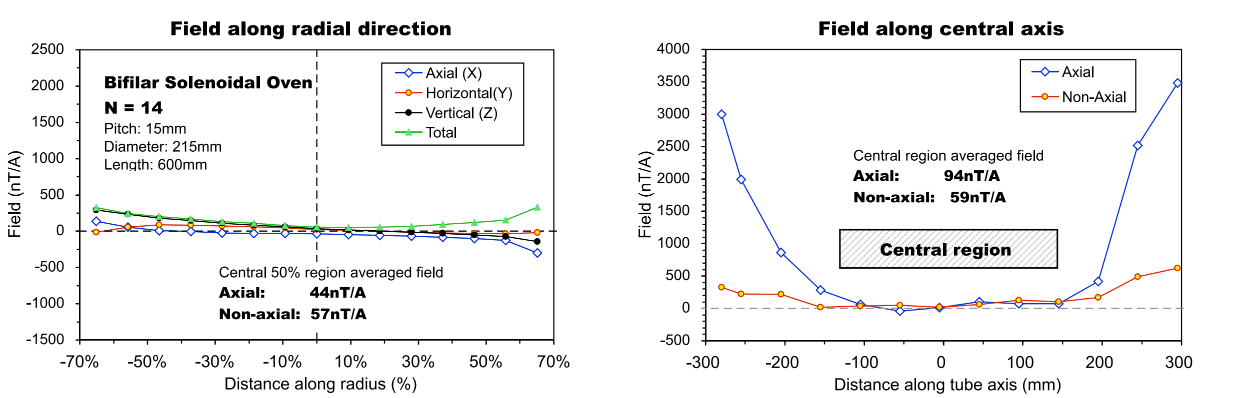

Figure 4. Uniform distribution of heater current generated field inside a bifilar solenoid wound oven (left) along the radial direction and (right) along the central axis. Large-diameter (215 mm) “oven” has been constructed with the same coils number 14 per diameter unit as that of the Sogo Fine-TD oven by using enameled copper wires instead of heating wire elements. As expected, a homogeneous and very low field (less than 300 nT/A) was observed in the entire measurable region (70% of radius, see Figure 4 (right)).

by misfeeding a current through the solenoidal coil designed for field generation for TRM experiments, rather than through the heating elements. We thank John Shaw for this opportunity to double check our data and further clarify other important aspects of building thermal demagnetizers. The newly measured data reproduced in this reply serve to correct that mistake. A bifilar solenoid wound oven yields uniform axially dominant magnetic field in general; its strength can be canceled out greatly by simply reducing its coils' pitch. However, in the case of the MMTD80-type wound oven, the field along the central axis is the lowest strength, and its value depends greatly on the degree of symmetry of the arrangement of heating elements rather than the number of heating elements. Along the radial direction, the noise field distributes unevenly, and the strength and spatial pattern of the field inside the oven are strongly controlled by both the number and arrangement of heating elements.

Acknowledgments

[10] We thank James Tyburczy of the journal's editorial board for providing useful advice and encouragements. We also thank an anonymous reviewer for the constructive and insightful review, which has greatly improved the clarification of our reply. We are extremely grateful to Yaoguo Li of Colorado School of Mines for helpful discussions and to Ching-Ren Lin, Kuo-Hang Chen, and Chun-Hung Lin of Institute of Earth Sciences (Taiwan) for assistance in measuring magnetic field in a MMTD80 oven.

References

Shaw, J. (2010), Comment on "A new high-precision furnace for paleomagnetic and paleointensity studies: Minimizing magnetic noise generated by heater currents inside traditional thermal demagnetizers" by Zhong Zheng, Xixi Zhao, and Chorng-Shern Horng, *Geochem. Geophys. Geosyst.*, *11*, Q11Y11, doi:10.1029/2010GC003211.

Zheng, Z., X. Zhao, and C.-S Horng (2010), A new high-precision furnace for paleomagnetic and paleointensity studies: Minimizing magnetic noise generated by heater currents inside traditional thermal demagnetizers, *Geochem. Geophys. Geosyst.*, *11*, Q04Y08, doi:10.1029/2010GC003100.