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Textur von supraleitenden YBaCuO Zylindern und ihre Abstoßungskraft auf einen induzierenden Permanentmagneten

Zur Untersuchung der Korrelation zwischen maximal möglicher Levitationskraft eines massiven YBaCuO-Zylinders, mit welcher ein induzierender Permanentmagnet abgestoßen wird, und der Qualität der Textur dieser YBaCuO-Zylinder wurden die Texturen verschiedener YBaCuO-Proben in einer Reihe von Messungen kartiert. Dabei wurde das Neutronen-Textur-Diffraktometer der Gruppe TUC/GKSS genutzt. Eine erste Korrelation zwischen Hubkraft und Textur konnte vorgestellt werden. Jedoch zeigen die Meßergebnisse eine beachtliche Streuung um die Tendenzkurve. Eine YBaCuO-Probe mit 94,5 N Hubkraft zeigte die beste Textur, während eine Probe gleicher Halbwertsbreite der Verteilung (FWHM), aber mit einer 94 %-Grenze der Orientierungen, welche um 7° größer ist, eine Hubkraft von nur 75,3 N erreichte. Diese Tendenz - kleinere Hubkraft bei verkippter Verteilung - wird auch durch Meßwerte von Proben bestätigt, die zwar weit von der Tendenzkurve entfernt sind, aber die gleiche Tendenz zeigen, wenn sie paarweise verbunden werden.

Texture of Superconducting YBaCuO-Cylinders and their Levitation Force Repulsing an Inducting Permanent Magnet

To investigate the relationship between the maximum possible magnetic levitation force of YBaCuO cylinders, with which they repel an inducting permanent magnet, and the texture quality of these YBaCuO cylinders, the textures of several YBaCuO specimens were measured in a number of series using the neutron texture diffractometer of the TUC/GKSS group. A first relationship between levitation force and texture could be presented. However, the measurement results were found to be scattered considerably around the tendency curve. A YBaCuO specimen of 94.5 N levitation force exhibited the best texture. A specimen of the same FWHM of the orientation distribution of the c-axes of the crystallites, but with a 94 % limit of the distribution of the c-axis deviations from the cylinder axis of the specimen increased by 7°, reached a levitation force of 75.3 N only. This tendency - smaller levitation force at tilted distribution - is also confirmed by specimens, whose measurement values are far from the tendency curve, but which show the same tendency when connected to pairs.

1 Introduction

At the Institut für Nukleare Festkörperphysik (Institute for Nuclear Solid State Physiks) of Forschungszentrum Karlsruhe (Karlsruhe Research Center) a superconducting magnetic bearing levitated magnetically on YBaCuO cylinders and serving for frictionless mechanical energy storage is being developed for demonstration in an application of high T_c superconductivity.

Also permanent magnetic materials could exclusively be used to build a magnetic bearing, but in that case stability of the bearing would be feasible in one dimension only (V. Jung, 1988), whereas the pinning forces associated with superconductivity allow a state of levitation to be achieved which is stable in three dimensions provided that currents are induced in the superconducting materials whose magnetic fields interact with the inducing field. This state of levitation with superconducting inductive conductors could be termed electrodynamic levitation in the standing position because the induction currents, once initiated, do not stop flowing in the state of superconduction.

The superconducting materials used must be characterized by a high current carrying capacity, which is achieved if the c-axis of YBaCuO runs normal to the direction of current, i.e. the superconducting cylinders in which the currents are induced must be very well textured (c-axis of YBaCuO in parallel to the cylinder axes). A fiber texture with 5° to 8° full width at half maximum peak hight (FWHM) will be sufficient. But there has been found a full orientation of the c- and the a-/b-axes. This can be seen from (102)/(012) pole figures of the YBaCuO specimens.

Several YBaCuO cylinders with oriented c-axes are needed to build a magnetic bearing. To avoid eddy currents the cylinders were cut to wedgeshaped pieces and set together to a ring. The important prerequisite of faultless performance of the ring for the superconducting magnetic bearing is that the textures of the YBaCuO pieces in the ring used are approximately identical.

The YBaCuO cylinders are grown in the melt at a peritectic temperature of 1100° C from 2 mm x 2 mm seed crystals through slow cooling and short melting. Pieces with textures greatly different from each other are generated in that process. Therefore, a multitude of specimens must be generated from which then an ensemble should be selected whose pieces are approximately identical in their textures and which, consequently, exhibit roughly the same current carrying capacity. Considering the dimensions of the specimens, which are about 13 mm thick only neutrons will be eligible for texture measurements which are being performed at the neutron texture diffractometer of the GKSS reactor, Geesthacht. As a matter of fact, it is not possible to draw a conclusion from the surface, which can also be examined by x-ray diffraction, to the texture in the volume.

The model used for demonstration is a flywheel store made with a storage capacity of 300 Wh. This is equivalent to the storage capacity of 25 Ah of a car battery. Thanks to the superconducting self-stabilizing magnetic bearing the storage losses are only very low.

Since the time when G. Bogner published his investigations (G. Bogner, 1988) it has been known to which high degree the current carrying capacity of superconducting thin YBaCuO layers is dependent on the orientation of the crystalline domains. However, the results of the investigations made on thin layers are not necessarily transferable to melt textured solid cylinders consisting of the same material (43 mm in diameter and 15 mm in height).

Therefore it is necessary and reasonable to find in a very great number of melt textured YBaCuO specimens a relationship between the texture of the specimens and their maximum repulsive force by which a permanent magnet is repelled through the currents induced by it in the superconductor. That means electrodynamic levitation without motion (V. Jung, 1988).

On the one hand, the full width at half maximum (FWHM) of the distribution of the c-axes of the crystallites in one specimen should not adopt too high a value. Values of 5° to 8° should be aimed at. Especially the tilt of the c-axes of neighbouring YBaCuO-domains should be as small as possible, because a tilt of 10° decreases the current carrying capacity in the boundary region between domains by a factor of 10 (R. Gross, 1993). On the other hand, the axis of distribution of the c-axes should agree as far as possible with the figure axis of the cylindric specimen (YBaCuO). Deviations by up to 2° of the axis of distribution from the figure axis are admissible, e.g., the full width at half maximum of the distribution of orientations of the c-axes of the cristallites in the specimen is not more than 6°. Finally the whole specimen volume should be textured if possible so that neither an irregular fraction nor other parasitic textures can be detected.

Obviously, it is not possible to fulfil these ideal conditions for all YBaCuO cylinders produced. But the very fact that some specimens do not fulfil these conditions enables us to find among a sufficiently great number of specimens the desired relationship between the texture and the maximum repulsive force by which an inducing permanent magnet is repelled through the superconducting currents induced in the superconducting YBaCuO cylinders when the permanent magnet approaches it.

Considering that many parameters undergo variations in the process of specimen preparation (H.J. Bornemann, 1993) and, moreover, any microcracks present in the specimens diminish the maximum possible repulsive force, the desired relationship between the texture width and the maximum repulsive force can be detected only in a very great number of specimens investigated, because the texture is only one of the variables to be optimized. Others, just enumerated here, are the oxygen loading and the rest of stoichiometry.

2. Texture Measurements by Neutron Diffraction at the Reactor of GKSS, Geesthacht

As a reactor for neutron scattering has not been available at the Karlsruhe Research Center for quite a long time (more than ten years), the texture measurements were performed at the neutron texture diffractometer at Geesthacht which was erected by H.-G. Brokmeier (H.-G. Brokmeier, 1995).

All reflections (00ℓ) in the diffraction spectrum of YBaCuO are eligible for the investigations to be made of the distribution of the c-axes orientations. However, these different reflections occur at very different intensities. For instance, the (005) reflection is more intensitive by approximately a factor of 7 than the (002) reflection. However, the (005) reflection is superimposed by the reflections (104) and (014). Only the (002) reflection is completely free of superpositions.

So, if it is to be found out whether the specimen to be measured contains an irregular fraction - that means an isotropic fraction -, this can be done preferable by use of the (002) reflection which implies a rather long duration of measurement because 630 points in total have to be measured on the half pole sphere at an angular distance on great circles of approx 6°. By refining the network, e.g. to 3° mesh width, the number of the measuring points required and hence the needed duration of measurement will be increased by a factor 4.

However, in order to be able to determine the full width at half maximum of the distributions of orientations it is sufficient to make twelve cuts through the pole sphere at the (005) reflection at $\Delta\phi$ = 30° distance, with intervals in χ of $\Delta\chi$ = 1°. The twelve cuts made in ϕ will be sufficient provided the deviation of the axis of distribution from the figure axis (cylinder axis) is small, e.g. less than 2°. As a matter of fact, at only 2° polar distance of the maximum of the distribution a rotation in ϕ by 30° corresponds to a movement on a great circle of the pole sphere of not more than 1°. So, in the vicinity of the maximum of the distribution, the resolution in ϕ would be the same as the resolution in χ. However, if the deviation of the axis of distribution from the cylinder axis is 6°, the steps in ϕ would have to be refined to 10° in order to obtain the same quality of resolution in ϕ as in χ in the maximum of distribution. But in that case it will mostly be sufficient to scan initially with a 30° screen in ϕ and then to refine the interval in ϕ near the maxima found (two in case of rotation the specimen around the cylinder axis by 360° in ϕ). The definitions of the angles ϕ and χ are evident from Fig. 1.

At each fixed setting of ϕ, χ is scanned within the range 110° > χ > 70° in 1° intervals. The distributions of the (104) and (014) reflections occur in the pole figure at sufficiently great pole distance so that the measurements for determinations of the position of the (005) maximum of distribution and the full width at half maximum (FWHM) of this distribution are not impaired by the distributions of the (104) and (014) reflections in the pole figure.

When the whole pole sphere is scanned at the (005) reflection it can be shown in which direction the a- and b-axes, respectively, are oriented because the reflections (104) and (014) are superimposed the (005) reflection in the diffraction spectrum of YBaCuO as has been stated before. But actually the a-axis cannot be discriminated from the b-axis in the Geesthacht measurement configuration. This is feasible only with the high-resolution time-of-flight diffractometer installed in Dubna where it was possible to find out that the a- and b-axes are not oriented with the same probability. In the pole figures measured there, of the reflections (102) and (012) the respective orientation in ϕ, rotated by 90° in ϕ, is represented with a 10 % fraction only. However it might be that only one orientation exists in ϕ and the rest of 10 % is attributable to insufficient resolution. Further measurements in Dubna will clarify this point.

When at the Geesthacht measurement configuration the (102)/(012) pole sphere is scanned (the two reflections cannot be separated in Geesthacht), one should not be suprised that a number of different distributions appear in the pole figures. It has to be taken into account that copper monocrystal monochromator also allows second order passage which means neutrons having half the wavelength. Consequently, the respective eight distributions of the reflections (211)/(121) and (212)/(122) as well as four distributions of the (116) reflection appear in the (102)/(012) pole figures.

3. Results and Discussion

Out of the many YBaCuO specimens measured only 12 were selected for an evaluation of the relationship existing between magnetic levitation force (repulsive force of the permanent magnet) and the sum of full width at half maximum (FWHM) of the distribution of orientations of the c-axes in the YBaCuO specimen and deviation of the axis of this distribution from the cylinder axis of the cylinder-shaped specimens (FWHM + $\Delta\chi$). It can be assumed that the specimens selected there have nearly no microcracks reducing the maximum levitation force achievable. Only specimens without microcracks and with nearly identical oxygen loading are selected for the relationship.

Among the specimens not represented in the diagram are also those whose full width at half maximum of orientation distribution of the c-axes is 6° and whose deviation of the axis of distribution from the cylinder axis is zero. However, for a number of reasons, these specimens do not achieve a correspondingly high levitation force. Neither has it been possible to find out in these specimens whether the whole specimen volume was textured. At measurements of a potential isotropic fraction of the specimen it should be taken into account that the intensity of the reflection in the maximum of distribution is greater by a factor of 1000 than under condition of equal distribution of the orientations over 2π of the half pole sphere. Although in each measurement of the texture the background between neighboring reflections in the diffraction spectrum of YBaCuO is measured too, this background adopts the same order of magnitude as the total intensity of distribution on the pole sphere, smeared over 2π, when it attains 1/1000 of the maximum of distribution on the pole sphere. Therefore, a 10 % isotropic fraction is hidden in the background and lies within the limits of error of the measured background. On the other hand, 30 % isotropic fraction can e.g. be clearly recognized.

It is quite obvious from pole figure measurements made on specimens selected to determine the relationship above between the levitation force and the texture that the whole specimen volume is textured and that neither parasitic textures occur. Only specimens for which this state (fully textured) can be proved are suited for representation of the relationship outlined above between levitation force and texture. But still, not all the measured values lie on the plotted curve, but scatter around it.

In connection with the representation of the relationship between levitation force and texture the question arises whether the deviations of the axis and the full width at half maximum of the distribution of orientations of the c-axes can be added linearly or whether the root of the sum of squares should rather be used. However, since in the case under consideration two Gaussian distributions are not superimposed, but the distribution is merely tilted, this suggests linear addition to be applied. When the deviation from the cylinder axis is added linearly to full width at half maximum (FWHM), the deviations of single measured values from the plotted curve indicative of the tendency are actually smallest.

The finding that specimens 33 mm in diameter (N 8 and N 10) lie well on the plot indicative of the tendency can be explained by the fact that all the levitation forces were measured using the same permanent magnet (H.J. Bornemann et al., 1997) equal in size and much smaller (25 mm in diameter) than the diameter of the large specimens of the M-series (43 mm in diameter). Thus, with identical textures and the rest of conditions being the same, levitation forces deviating only slightly from the plotted curve could result for the N-series (33 mm in diameter) and for the M-series (43 mm in diameter). A first relationship indicated between the levitation force and the texture has been represented in Fig. 2a.

It is evident from the cuts through the pole spheres of specimen M 37 (Fig. 3c) and specimen M 43 (Fig. 4b) that these cuts are not well Gaussian-formed. This means that the value $\Delta\chi +$ FWHM cannot be the suitable value for comparison of the levitation forces of the specimens. To take into account this circumstance, the cuts through the maxima of the c-axis orientation distributions were assumed to be rotational symmetrical. This assumtion was necessary, because only cuts through the maximum of distribution on the pole sphere have been measured in intervals in χ of 1° and no equal-area-measurement with a grid of 1° mash width had been available due to the very long measuring time needed. In this way deviations from the Gaussian form at the foot of the distributions become more important, because the deviations are now expanded over a bigger small circle on the pole sphere. Thus, the values of the cut through the distribution on the pole sphere were distributed on equal areas on small circles around the axis of the c-axis orientation distribution. This axis of distribution was in oblique position to the cylinder axis of most specimens, tilted by 1° ... 7° against the cylinder axis of the specimens. To get the distribution of c-axis deviations from the cylinder axis of the cylindric YBaCuO specimen, on small circles around the cylinder axis, this rotational symmetric distribution has been cut and the values on these small circles around the cylinder axis have been summed, as shown in Fig. 2b. The result of these sums is a new distribution, namely, the distribution of c-axis deviations from the cylinder axis of the specimen, as shown in Fig. 2c for specimen M 39. This distribution (from M 39) is generated by a Gaussian-formed cut through the pole sphere at the maximum of distribution. By this Gaussian-formed cut 94 % of the c-axis orientations are lying beyond $\Delta\chi$ + FWHM. However, in the distribution resulting for specimen M 37 (formed as above for specimen M 39) only 81 % of the c-axis orientations are lying beyond the limit $\Delta\chi$ + FWHM, as shown in Fig. 2d. In the same way as above, the new distributions are generated for the selected specimens M 39, M 40, M 37, M 41, M 21, M 13 and M 3. These specimens were selected, because in the (002) pole figures, e.g. Fig. 3a, measured with a 6° grid, no parasitic c-axis orientations were found. From these specimens three values, $\Delta\chi$ + FWHM, 94 % limit and 97 % limit of all generated distributions were plotted in Fig. 2e. The best value for plotting the levitation Force F_ℓ versus the above limits of c-axis distributions seems to be the 94 % value. For specimen M 39 this value (94 %) coincides with the value $\Delta\chi$ + FWHM. This means, 94 % of all c-axis deviations from the cylinder axis of the YBaCuO-cylinder are within the limit $\Delta\chi$ + FWHM. For specimen M 40, however, it is not clear why this specimen produces a high levitation force of 90.3 N, having a 94 % value in the c-axis distribution at 18.5° distance from the cylinder axis of the specimen M 40. It might be that in the c-axis orientation distribution the tilt between individual crystalline domaines is very small, or the c-axes are tilted in same planes with the cylinder axis, as discussed below.

To present also a survey of the kind of texture of the specimens, pole figures and cuts through the pole spheres of only two specimens were selected which differ very distinctly in terms of their levitation forces and textures. The pole figure of the (002) reflection of specimen M 37 as well as two cuts through the pole sphere which are orthogonal to each other have been represented in Figs. 3a through 3c. This specimen M 37 has twice the levitation force of specimen M 43 whose (002) pole figure and cuts through the (005) pole sphere have been represented in Figs. 4a through 4b.

A comparison of Figs. 3b and 3c with Fig. 4b makes evident that the full width at half maximum (FWHM) of specimen M 37 and M 43 differ but slightly from each other. But the deviations of the axes of distributions from the cylinder axes differ greatly for specimens M 37 and M 43. Whereas in specimen M 37 the axis of distribution differs from the cylinder axis by 2°, the corresponding deviation of the axis of specimen M 43 is about 7°. This deviation of the axis of orientation distribution from the cylinder axis ($\Delta\chi$) should be one reason that the levitation force of specimen M 43 is only half that of specimen M 37. Even more important is the fact, that the integral counting rate of the cuts through the pole sphere of specimen M 43 (Fig. 4b) has nearly half the value of that of the cut of specimen M 37 (Fig. 3c). This means - at same beam size and same specimen size and at same counting time - that there exist other parasitic c-axis orientations in the specimen M 43, as can be seen from the (002) pole Figure (Fig. 4a). A third reason might be an isotropic fraction of specimen M 43, which could not be measured within the limited measuring time.

It might be that a full width at half maximum of the distribution of orientations of the c-axes in the specimen of about 6° already allows the maximum of magnetic repulsive force to be achieved provided the axis of distribution of the c-axes is not in an oblique position with respect to the cylinder axis of the specimen. But this is not certain at all and further investigations involving narrower distributions of the c-axes in a specimen and less obliquity of the axis of distribution are necessary to clarify this question (Bornemann et al., 1996).

A great number of well textured specimens free of microcracks would still have to be examined, in particular their magnetic repulsive force and texture width (FWHM) as well as the obliquity of distribution with respect to the cylinder axis. Then an unambiguous relationship could be determined between obliquity, texture width (FWHM), grain size, and repulsive levitation force. Especially the isotropic fractions of the specimens have to be investigated because these isotropic fractions of the cylindric specimens contribute a neglegible part to the levitation force of the YBaCuO-cylinders and therefore diminuate the maximum possible levitation force of the specimens repulsing the inducting permanent magnet with which the repulsing force has been measured.

Further measurements of the textures and the levitations forces of melt textured YBaCuO specimens are planned. Particular attention shall be paid to the determination of a possible isotropic fraction in the specimens, as stated above. The isotropic fraction, i.e. the specimen fraction at which all orientations of the c-axes of the crystallites on the pole sphere are equally probable, has not yet been measured unambiguously, as the integral over the orientation distribution of the c-axes distributed equally over the entire pole sphere hardly reaches the magnitude of the background in the reflex spectrum of the neutrons. An increased measuring time, however, allows to determine this possible isotropic, i.e. irregular fraction of the specimens. It is assumed that this still unknown isotropic fraction of the specimens considerably contributes to the scattering of the measurement results around the tendency curve. The isotropic fraction reduces the maximum possible levitation force, as the superconducting currents in the YBaCuO specimens mainly flow in the well-textured parts of the superconducting material and the isotropic fractions hardly contribute to the superconducting currents and therefore to the levitation forces of the specimens.

Another problem is the orientation of the c-axes of the crystallites with respect to the direction of the superconducting current and to the direction of the produced magnetic field. It is possible that at different local orientation distributions of the c-axes, but with the same integral distribution and with the same FWHMs, in a first case the c-axes are normal to the superconducting current direction, because the c-axes of the tilted crystallites lie in the same plane with the cylinder axis of the cylindric specimen; and in a second case the c-axes are tilted in a plane parallel to the cylinder axis and having a distance to it smaller than the radius of the cylindric specimen. In the second case the maximum possible superconducting current is decreased heavily and therefore the levitation force too. In this second case the c-axes of the crystallites are no longer normal to the direction of the superconducting current. But in the first case the c-axes are normal to the current direction and the c-axes of the crystallites only are tilted against the magnetic field vector. By this fact the reduction of the maximum possible superconducting current is very small only (H.J. Bornemann et al., 1993). These differences in orientation with respect to the superconducting current direction would be a further reason for the large scattering of the measured data around the tendency curve, shown in Fig. 2a and 2e. Fig. 5 shows the different tilting directions of the c-axes of the crystallites.

To investigate a possible case of different tilting directions of the distribution axes of c-axes distributions of individual parts of a YBaCuO cylinder the specimen M 39 has been cut into 9 pieces, one central piece and 8 pieces at the periphery of the specimen. The result of the measurement of the local texture shows that the pieces lying on the diagonal direction of the rectangular seed crystal show the largest deviations of the c-axes from the cylinder axis. But no evidence for a preferred tilting direction of the distribution axes in same planes with the cylinder axis has been found. The arrows in Fig. 6 indicate the tilting directions of the axes of c-axis orientation distributions of the 9 pieces of specimen M 39.

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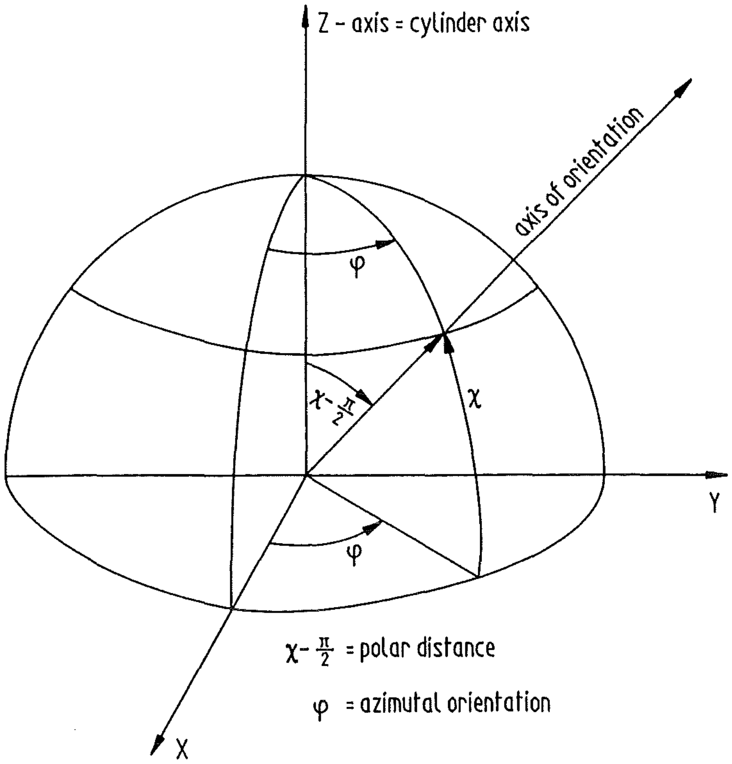


Fig. 1 Definition of the angles ϕ and χ. The z-axis is identical with the cylinder-axis of the cylindrical YBaCuO-specimens. In these specimens the orientations of the axes of distributions of the c-axes of the crystallites must not coincide with the cylinder-axes of the speximens. The polar distance of the axes of orientation distribution is χ-π/2. The azimutal orientation of the axes of orientation is ϕ.

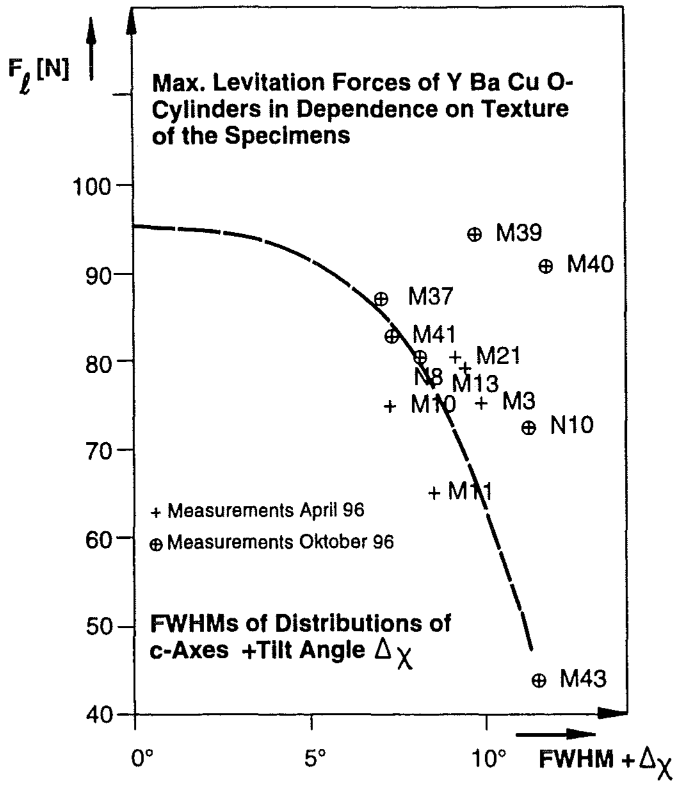
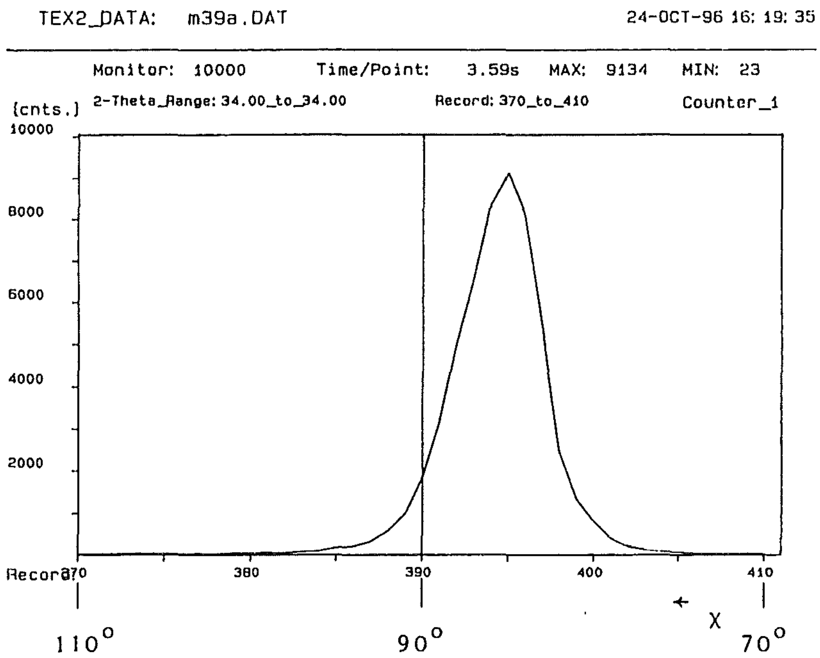


Fig. 2a Correlation between measured levitation force F_ℓ and the sum of the FWHM of the distribution of the c-axes of the crystallites in the specimens and the tilting angle $\Delta\chi$ with respect to the cylinder axes of the specimens (FWHM + $\Delta\chi$).



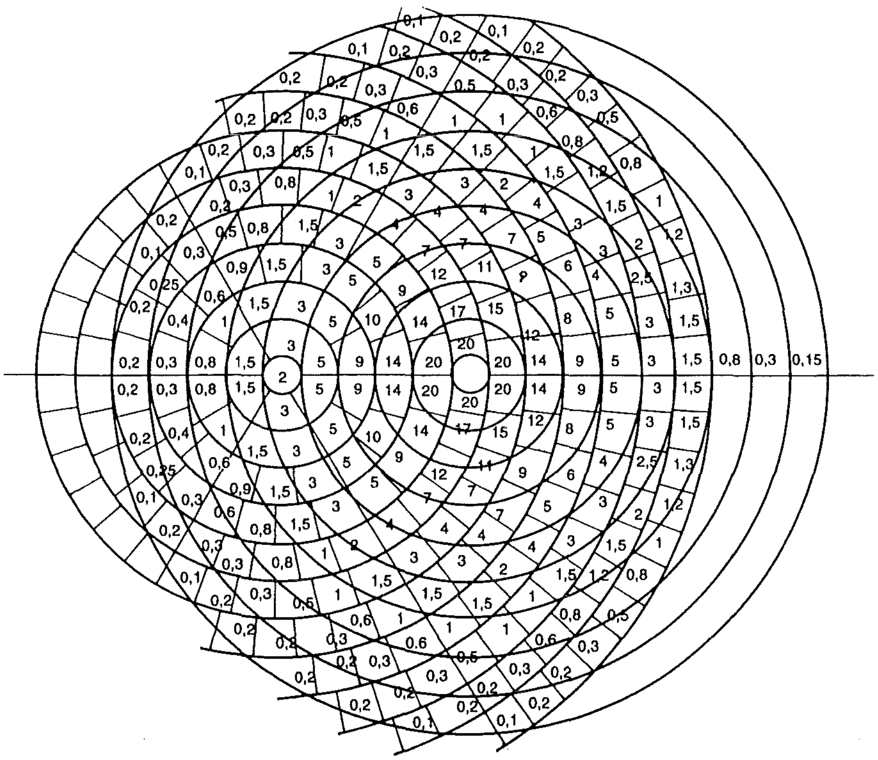
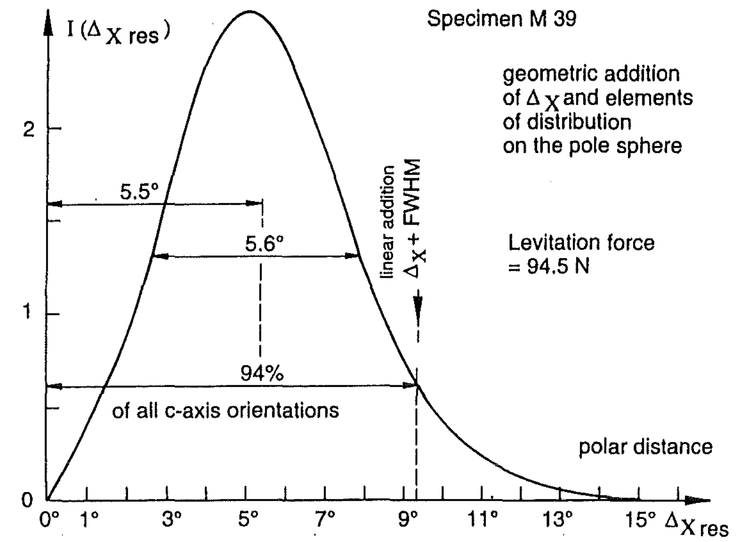
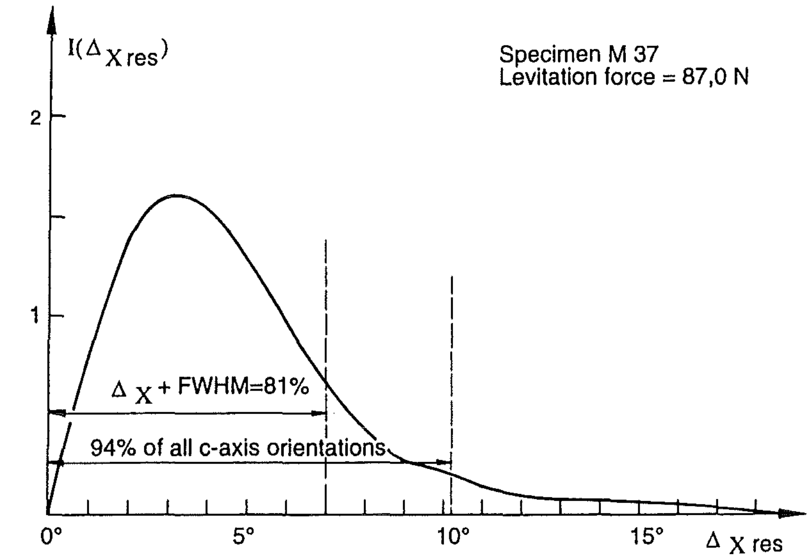


Fig. 2b The cut through the c-axis orientation distribution of specimen M 39 was assumed to be representative for the whole orientation distribution and to be rotational symmetric around the distribution axis. Cutting this distribution on small circles around the cylinder axis of the specimen, a new distribution is generated by summing up the individual values on small circles around the cylinder axis. The individual sums are the values of the deviation distribution of the c-axes from the cylinder axis of the specimen. Center at left: Cylinder axis of the specimen, center at right hand side: axis of the c-axis distribution on the pole sphere.





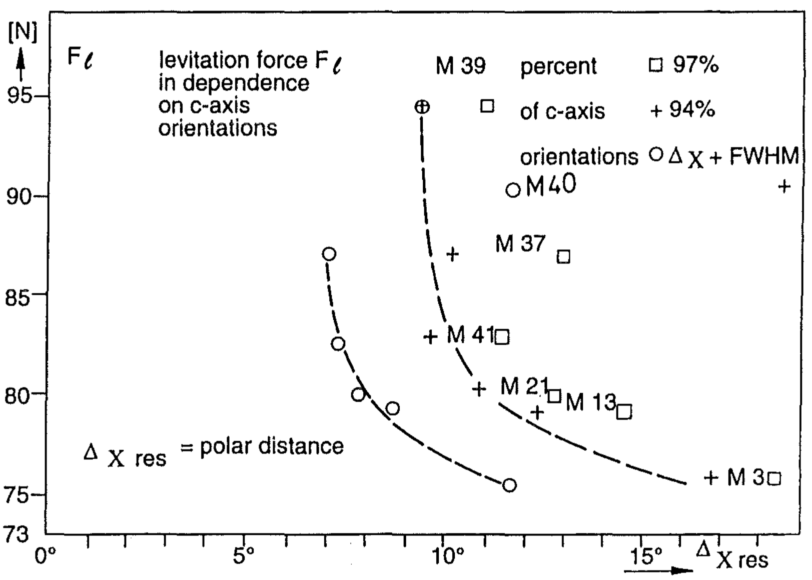
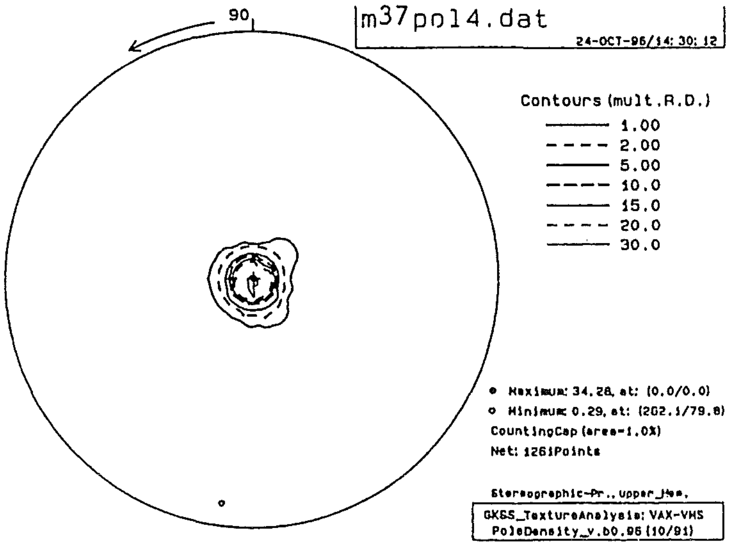


Fig. 2c Distribution of deviations of the c-axes from the cylinder axis of specimen M 39.

Fig. 2d Distribution of deviations of the c-axes from the cylinder axis of specimen M 37.

Fig. 2e Correlation between levitation force F_ℓ and the values $\Delta\chi$ + FWHM, 94 % limit and 97 % limit of orientation deviations of c-axes from the cylinder axis of the selected specimens M 3, M 13, M 21, M 41, M 37, M 40 and M 39. For these selected specimens, which are free of other parasitic c-axis orientations, the best correlation has been fitted by the 94 % limit of all c-axis orientations.



<u>Fig. 3a</u> (002) pole figure and (005) pole figure of the specimen M 37 (YBaCuO). The diameter of this specimen is 43 mm, the extension in direction of the cylinder axis is 15 mm. No isotropic fraction has been found in this specimen. The FWHM of the orientation distribution of the c-axes of the crystallites in the specimen is about 5°, the polar distance of the axis of distribution from the cylinder axis is 2° only. The four secondary maxima in the (005) pole figure are caused by the (104) and (014) reflections, superimposed to the (005) reflection.

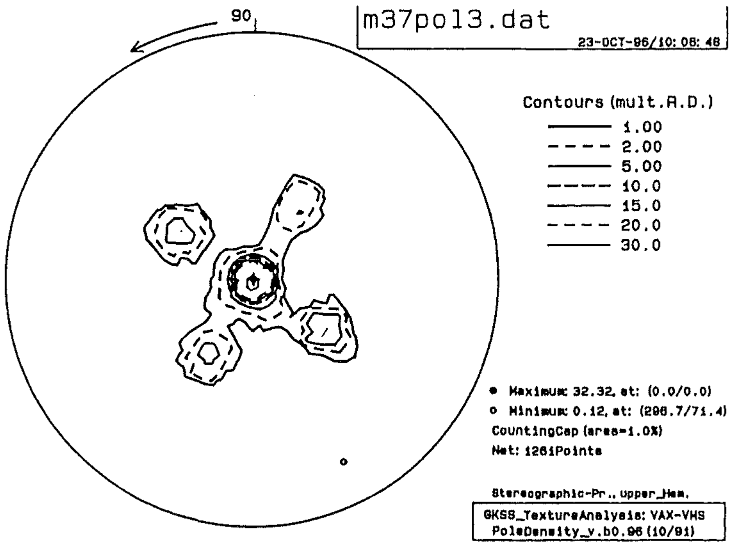


Fig. 3b Cut through the (005) pole sphere at ϕ = 15° from χ = 110° to χ = 70° of the specimen M 37. The angle χ was passed at 1° intervals and the angle ϕ at 15° intervals. The maximum of the distribution has not been met by this cut.

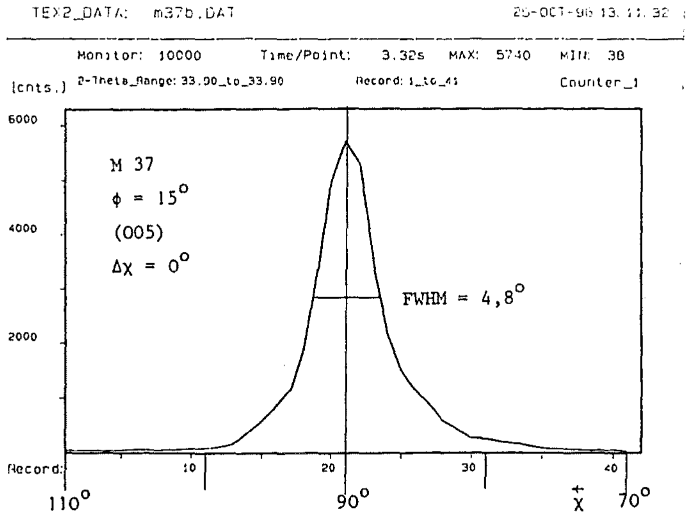


Fig. 3c Cut through the pole sphere of the specimen M 37 at ϕ = 105° from χ = 110° to χ = 70°. The intervals are the same as in Fig. 3b. The maximum of the distribution has been met by this cut orthogonal to that of Fig. 3b.

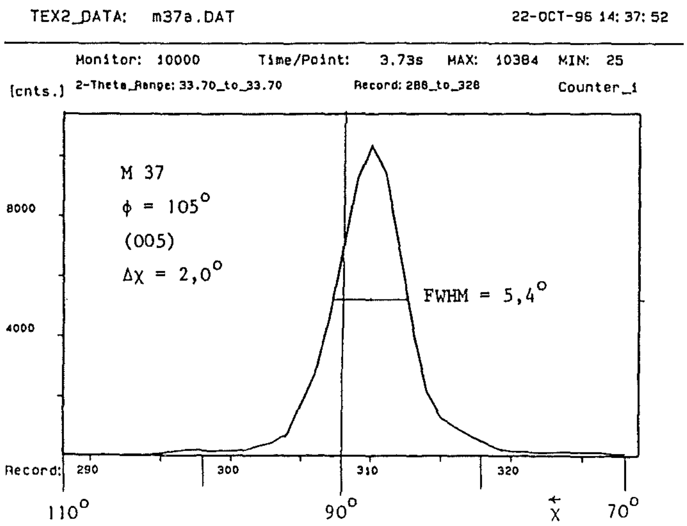


Fig. 4a (002) pole figure of specimen M 43. It is evident from this pole figure that the axis of distribution of the c-axes of the crystallites is tilted by 7° with respect to the cylinder axis of specimen M 43. A small contribution of a- and b-axis orientations is evident from the four distributions near the aequator of the pole sphere. The orientation in the cylinder plane is evident from the (005) pole figure as in Fig. 3a.

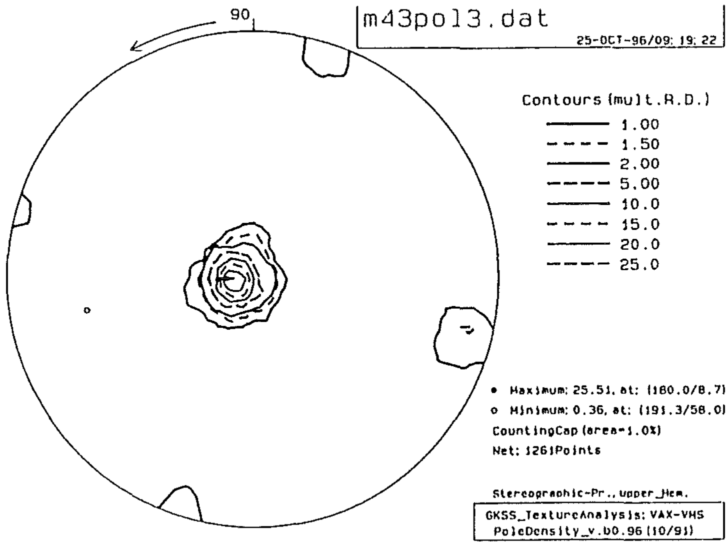
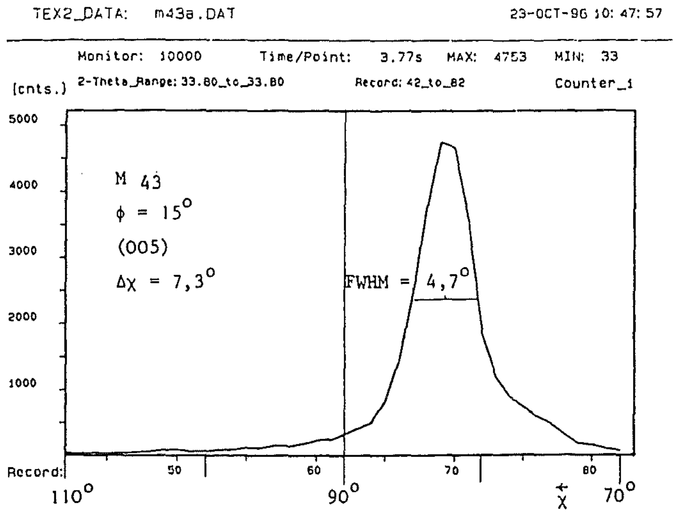
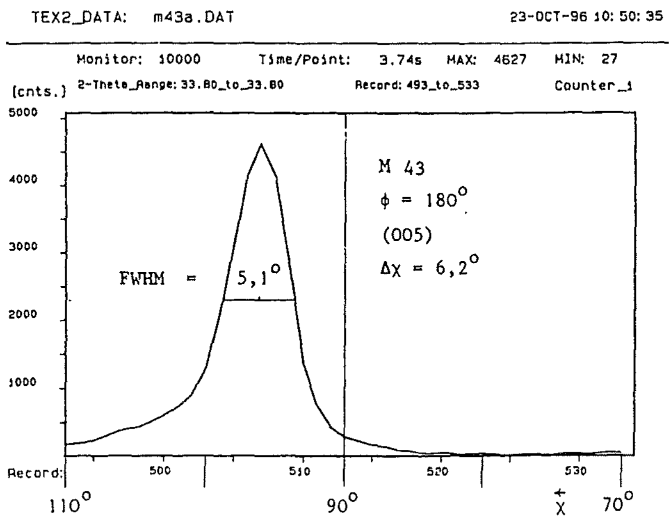


Fig. 4b The FWHM of the distribution of directions of the c-axes of the crystallites in the YBaCuO specimen M 43 is about 5°. Two cuts through the pole sphere of (005) pole figure are shown at $\phi = 15°$ and at $\phi = 180°$. The angle χ was passed at 1° intervals from $\chi = 110°$ to $\chi = 70°$ and the angle ϕ at 15° intervals. From the cuts it is evident that the tilting angle of the axis of distribution of the c-axes of the crystallites with respect to the cylinder axis of the specimen M 43 is about 7°.





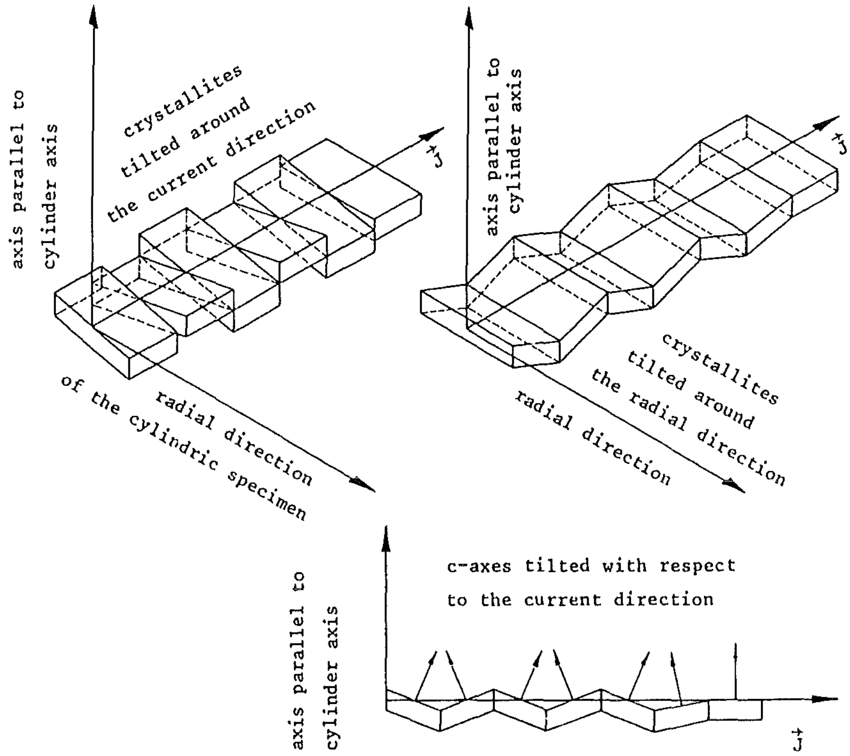


Fig. 5 Different tilting axes of the crystallites in the YBaCuO specimens. 1.: Tilting around the current direction of the induced superconducting current (left hand side). 2.: Tilting around the radial direction of the cylindric specimen (at right hand side and at bottom). In the first case the c-axes of the crystallites allways are normal to the current direction. In the second case the c-axes of the crystallites are tilted with respect to the current direction of the induced superconducting current, and the c-axes no longer are perpendicular to this current direction. In case that the induced superconducting current penetrates the grain boundaries, in the second case the induced current is reduced because of the obliquity of the c-axes. In the first case (left hand side) the induced superconducting current will hardly be influenced by tilting of the c-axes around the current direction with respect to the vector of the magnetic field because the c-axes of crystallites remain normal to direction of superconducting current.

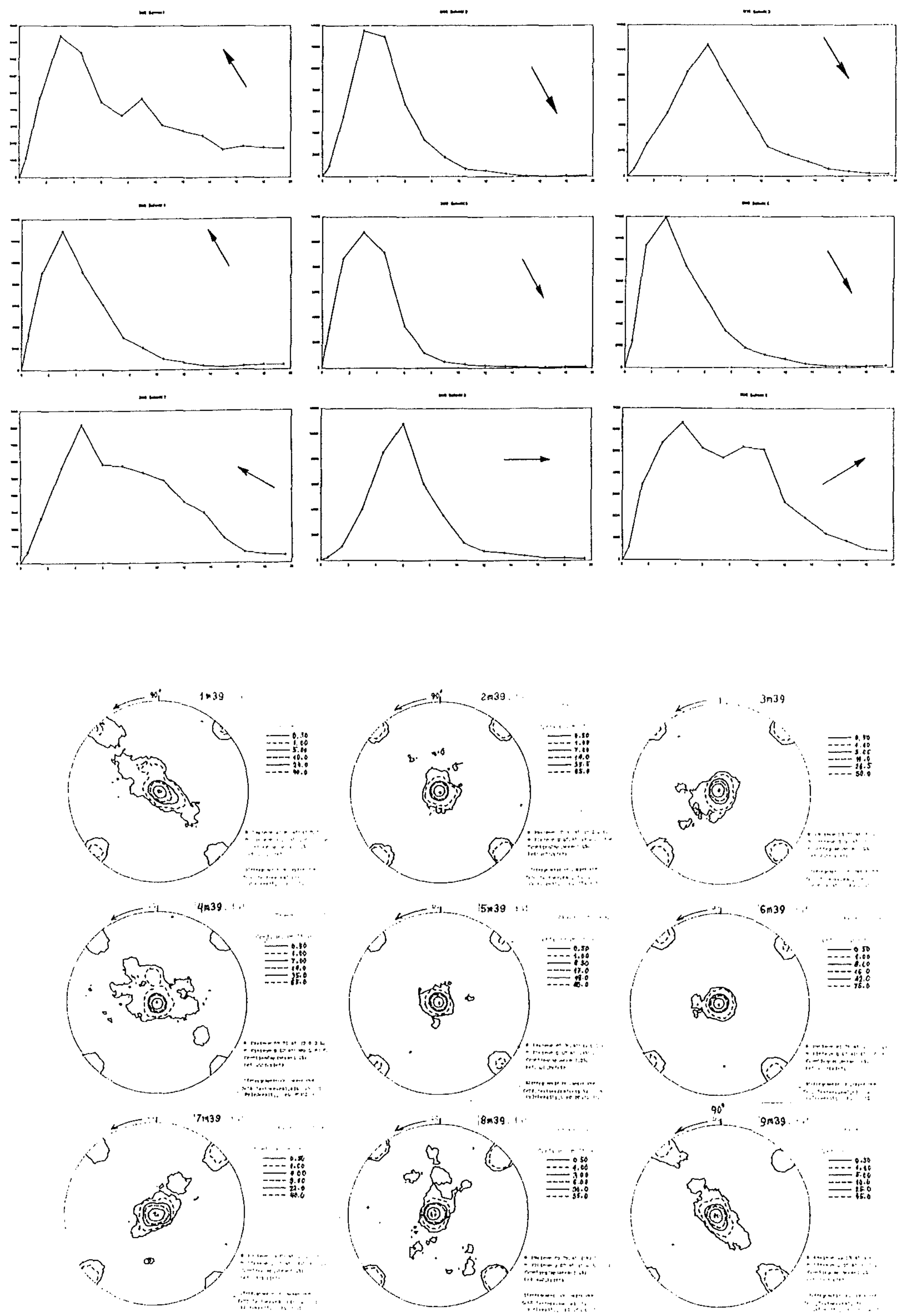
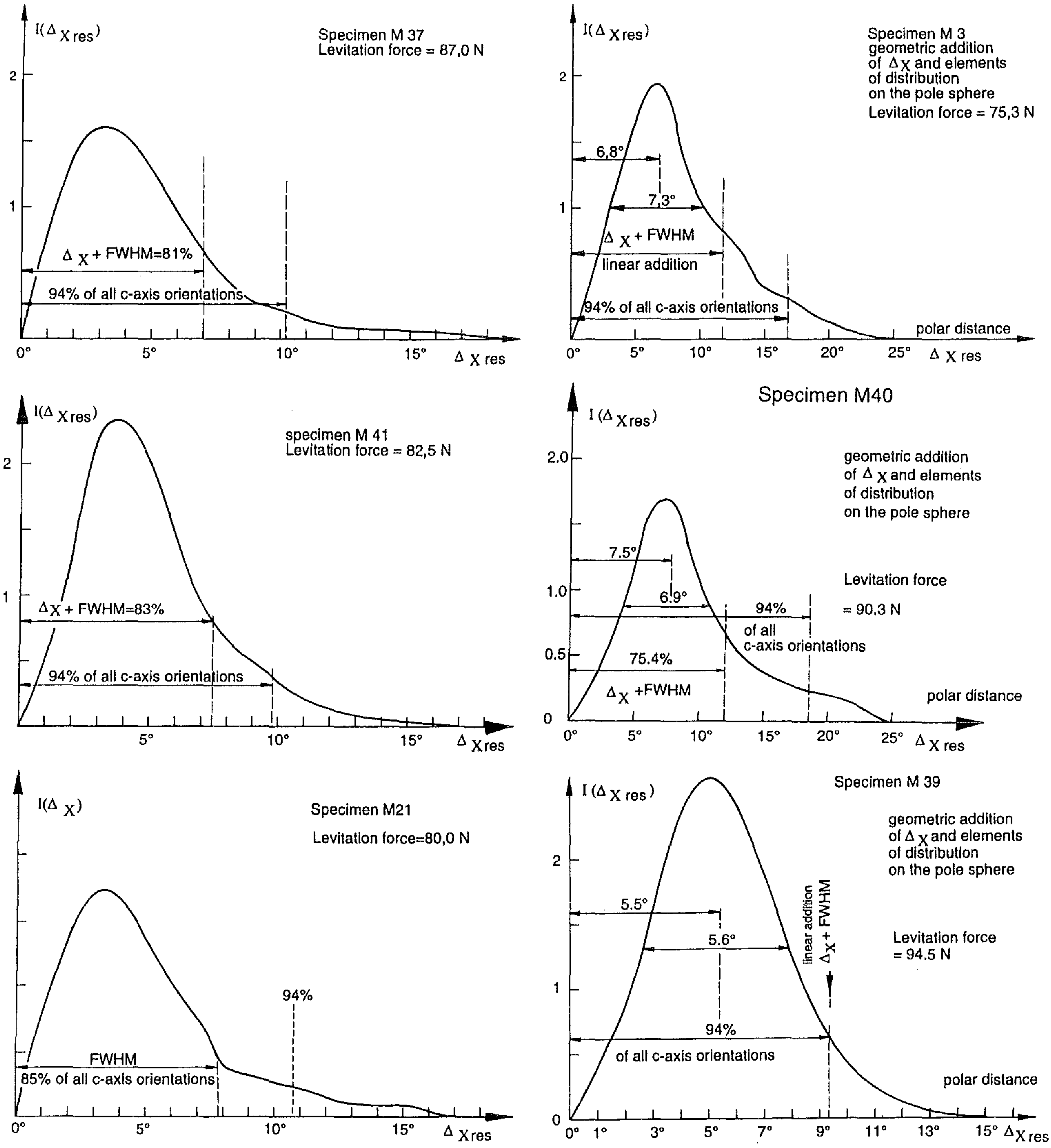


Fig. 6 The specimen M 39 has been cut into 9 pieces for measuring the local texture. The 9 distributions of angular deviations of the c-axes from the cylinder axis of specimen M 39 are shown above. The central piece in the middle has the smallest deviations of the c-axes from the cylinder axis. A small a/b-axis orientation fraction is evident from the 9 (002) pole figures at bottom. This fraction is increased from 1 % in the middle to 2 % at the pieces lying in the diogonal direction of the rectangular seed crystal. These pieces show the largest c-axis deviations from the cylinder axis of specimen M 39.



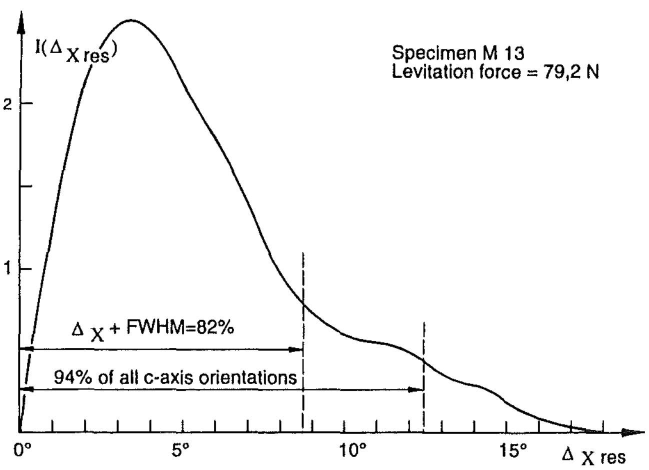


Fig. 7 Comparison of the distributions of the c-axes deviations from the cylinder axes of the specimens M 37, M 41, M 21, M 13, M 3, M 40, and M 39.