# THE RELATIONSHIP BETWEEN THE APPEARANCE OF FILAMENTS AND THE ACTIVE REGION MAGNETIC FIELD DYNAMICS

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ABSTRACT. A comparative study of magnetograms and $H_\alpha$-filtergrams has led to the conclusion that the magnitude of the sustaining magnetic field has an essential role during the appearance and persistence time of a filament inside the active region. As the characteristic of the magnetic field we have chosen the distribution of the longitudinal magnetic field gradient in the close vicinity of the polarity inversion line. The study carried out in this paper provided a necessary condition for the appearance of a filament within the active region, namely a shift of the distribution grad $H_\parallel$ towards low values of the gradient and the homogeneity of the polarity inversion line with respect to the magnetic field, in which case a maximum value of grad $H_\parallel$ should not exceed a certain limiting value.

СВЯЗЬ ПОЯВЛЕНИЯ ВОЛОКОН С ДИНАМИКОЙ МАГНИТНОГО ПОЛЯ АКТИВНОЙ ОБЛАСТИ: На основе совместного исследования магнитограмм и $H_\alpha$-фильтрограмм сделан вывод о существенной роли величины поддерживающего магнитного поля в процессе появления и существования волокна внутри активной области. В качестве характеристики магнитного поля использовано распределение градиента продольного магнитного поля в ближайшей окрестности линии раздела полярностей. В результате проведенного исследования получено необходимое условие для появления волокна внутри активной области: сдвиг распределения grad $H_\parallel$ в сторону низких значений градиента и однородность линии раздела полярностей по магнитному полю, причем максимальное значение grad $H_\parallel$ не должно превышать определенного предельного значения.

VZŤAH MEDZI VZNIKOM FILAMENTOV A DYNAMIKOU MAGNETICKÉHO POĽA AKTÍVNEJ OBLASTI: Na základe porovnávacej analýzy magnetogramov a H-alfa filtergramov bola zistená podstatná úloha hodnoty "nosného" magnetického poľa filamentu a to tak v procese vzniku ako aj jeho existencie vo vnútri aktívnej oblasti. Gradient pozdĺžnej zložky magnetického poľa a jeho rozdelenie pozdĺž neutrálnej

línie magnetického poľa bol vybraný ako charakteristika poľa. Z analýzy plynie že nutnou podmienkou pre vznik filamentu vo vnútri aktívnej oblasti je posun rozdelenia grad $H_{\parallel}$ k nízkym hodnotám gradientu, ďalej magnetická rovnorodosť neutrálnej čiary a maximálna hodnota grad $H_{\parallel}$ nesmie byť väčšia ako definovaná hraničná hodnota gradientu.

Active region filaments are maintained against gravity by a magnetic field whose lines of force are anchored in regions of opposite polarity on both sides of the filament. Therefore, filaments are normally observed above the inversion polarity line of a longitudinal magnetic field (IPL) Dependence of the formation and stability of filaments on the underlying field structure is an important problem of the physics of solar prominences. Although much has been understood qualitatively, the question of how this dependence can be represented quantitatively still remains open. It is essential here to choose appropriate parameters that characterized the magnetic field configuration. It is possible to formulate the following problem: Does the inversion polarity line differ in certain magnetic field parameters in the cases of existing and non-existing filaments, and is it possible to use these parameters differences for predicting the appearance or disappearance of filaments?

It is natural to choose as characteristic of an underlying magnetic field the value of horizontal gradient of a longitudinal magnetic field near the IPL (grad $H_{\parallel}$). It should be borne in mind, however, that the IPL and the filament are extended features. Therefore, solving the problem requires the distribution of grad $H_{\parallel}$ along the entire IPL length, rather than the grad $H_{\parallel}$ measured at individual points. This condition is satisfiable if grad $H_{\parallel}$ is measured in the nearest vicinity of the IPL. In our investigations this was actually achieved by using mainly magnetic field isolines $\pm$30 Gs for determining the gradient (1). Although the measured gradients may not belong to field lines directly maintaining the filament, they, nevertheless, generally characterize the configuration of a magnetic field in which a filament is being formed.

Observational material included $H_{\parallel}$ -magnetograms obtained with the panoramic magnetograph of the Sayan observatory in the 5250 and 5253 Å lines of Fe I. The time resolution of the magnetograms used was about 1 day while the spatial resolution was determined by the magnetograph aperture, 1".8 3".6. Filtergrams at the center of the H$\alpha$-line were taken with the large coronograph and with the horizontal solar telescope AZU-5, as well as H$\alpha$-filtergrams of the full disk of the Sun obtained within the "Solar Service" Program by other observatories, were used. The spatial resolution of the filtergrams was 2 to 3".

The observations were handled in the following manner. We drew on the magnetogram the IPL which was divided into about equal intervals and, then, grad $H_{\parallel}$ was determined on the boundaries of these intervals in a direction normal to the IPL. After that, we transferred to the magnetogram the filament position from the filtergrams. We studied only the filaments which were loca-

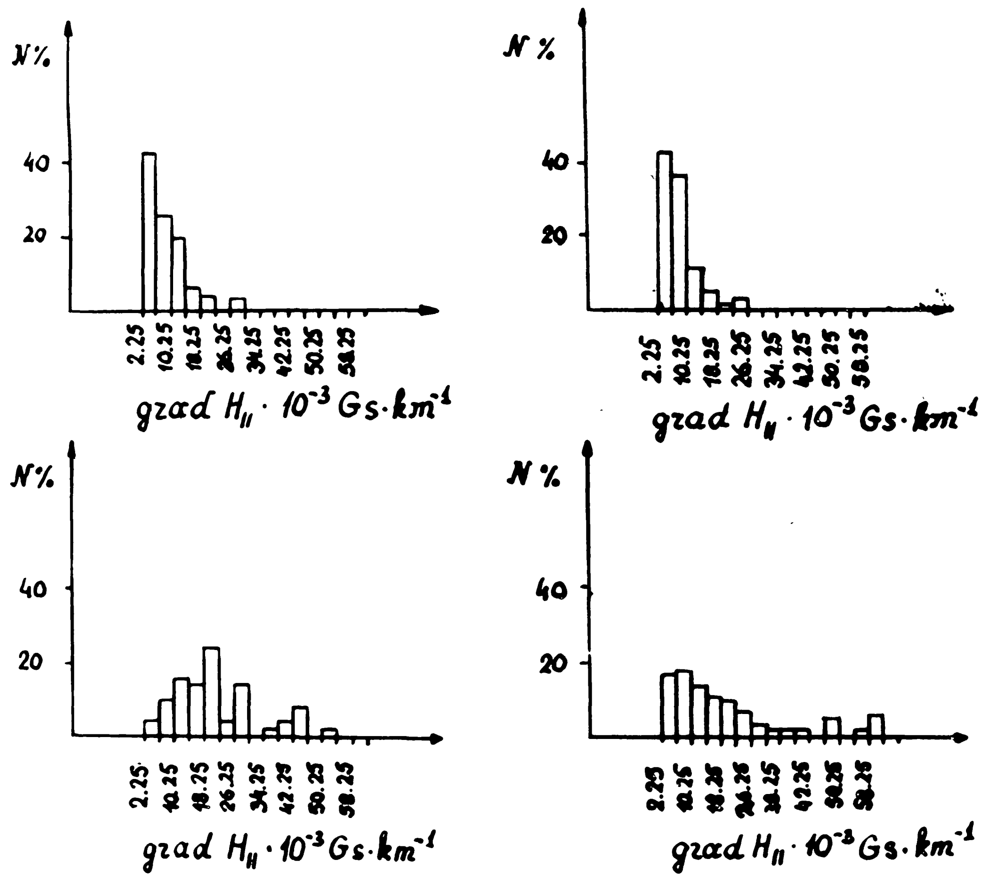


Fig. 1: The grad $H_{\parallel}$ -distribution histogram for the cases with or without a filament.

a - for active regions SD 312/82 and 3322/82;

b - for active regions SD 243/78 and 227/79.

ted inside active regions or on their boundaries. In order to avoid a strong influence of magnetic field projection effects, we chosen the active regions located not farther than $35^{\circ}$ from the disk center. The measured results were used in constructing the histograms of the number of events (N), with the filament being present or absent depending on grad $H_{\parallel}$ (Figure 1). The histogram shown in Figure 1a was constructed for active regions SD 312/82 (the observations were made on 9 and 11-14 September 1982) and SD 322/82 (on 18 and 20 September 1982) for the 5253 Å line of Fe I. All in all, we measured 67 scans in the portions of the IPL with the filament present and 50 scans in those without filaments. Figure 1b presents analogous histograms for active regions SD 243/78 (2-4 September 1978) and SD 227/79 (23-24 May 1979) from the 5250 Å line of Fe I. 61 scans were measured in areas involving a filament and 126

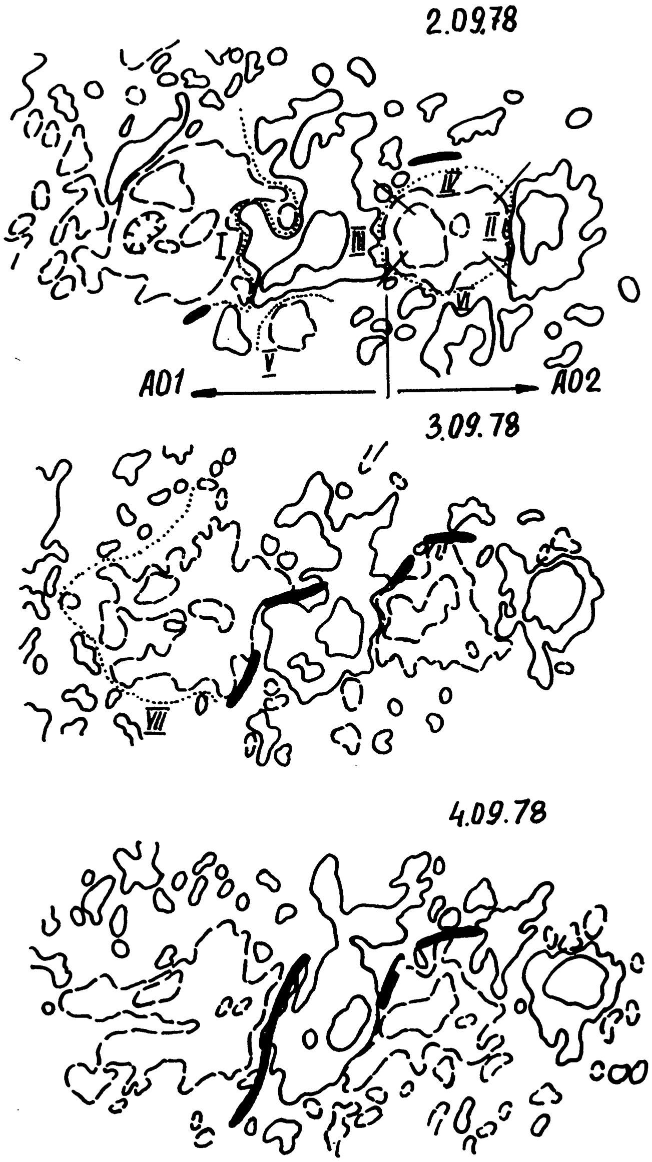


Fig. 2: Longitudinal magnetic field maps. Only the $\pm$ 30 and $\pm$ 200 Gs isolines are drawn. Roman figures denote the IPL number, and thin straight lines outline the IPL boundaries. 1 - preceding polarity, 2 - following polarity, 3 - inversion polarity line, and 4 - filament locations.

scans with no filament involved. The form of the histograms suggests the conclusion that the filaments line in regions with smaller gradients. The measurements were used to calculate the median distributions of grad $H_{\parallel}$. For data presented in Figure 1a, $\overline{\text{grad } H_{\parallel}}$ = 0.0074 Gs km$^{-1}$ in the area with a filament and $\overline{\text{grad } H_{\parallel}}$ = 0.0222 Gs km$^{-1}$ in areas devoid of filaments. The greatest measured value of the gradient along the IPL portion involving a filament was 0.0276 Gs km$^{-1}$. The corresponding values for data presented in Figure 1b, were 0.0072 Gs km$^{-1}$, 0.0202 Gs km$^{-1}$ and 0.0231 Gs km$^{-1}$. Thus, although the results obtained were based on magnetic field measurements taken in different lines, the agreement between them may be regarded as good, the more so as $H_{\parallel}$ -measurements taken in both lines (2-3) were not to differ substantially. However, we leave out of our discussion here this issue. The main point of our interest here is that the grad $H_{\parallel}$ -distributions along the portions with and without a filament are shifted with respect to each other and there exists a limiting value of grad $H_{\parallel}$ so that when it is surpassed, no filament appears. Of course, in order to be firmly confident requires far broader lines of statistical evidence but the results obtained induce us to hope that the technique described here could give an answer to the first part of the problem.

We have also investigated the possible relation between the variations in grad $H_{\parallel}$ -distribution near the IPL and the filament occurrence. For the analysis we chose the observations relating to a complex or two closely spaced, old and young, active regions which exhibited a filamentation during the period under investigation. The "Solnechnye dannye" Bulletin lists the two active regions as entry 243 (4). Figure 2 presents $H_{\parallel}$ -magnetograms of the complex of activity showing the IPL and filaments. A dark feature of $\gtrsim$ 4-5" width and $\gtrsim$ 20" length, lying on the IPL and having a lifetime over 24 hr was considered to be a filament.

Results of magnetogram processing are presented in Figure 3 in the form of grad $H_{\parallel}$ -distribution histograms for each IPL studied (only IPL I-III data are given) and each day of observation separately. The mean gradient value, $\langle \text{grad } H_{\parallel} \rangle$ , and the maximum gradient value, $\delta$, were taken as the parameters characterizing the distribution.

Let us consider the behaviour of the distribution parameters for separate IPL and the relation between the distribution and the appearance or absence of a filament. On 2 September IPL 1 was characterized by the following values of the parameters: $\delta$ = 0.0772 Gs km$^{-1}$ and $\langle \text{grad } H_{\parallel} \rangle$ = 0.0219 Gs km$^{-1}$. at its southern end, there was a small segment with $\delta$ = 0.0046 Gs km$^{-1}$ and $\langle \text{grad } H_{\parallel} \rangle$ = 0.0042 Gs km$^{-1}$ which showed on 1 and 2 September a filament of $\sim$ 20" length. On 3 and 4 September the histogram was shifted towards lower gradient values whole the value of decreased to 0.0248 Gs km$^{-1}$ on 3 September and continued so on 4 September. Such variations in the distribution were accompanied by an increase of the length of the existing filament, the appearance of a new filament northward along IPL, a "migration" of the filaments coming closer together and, finally, by their "merging together". On IPL IV the situation differed only in that during the observation interval the IPL increased in length, which, however, did not lead to any substantial increase of the originally small values of $\delta$ and $\langle \text{grad } H_{\parallel} \rangle$. As far as the filament evolution is concerned, the picture was similar to one discribed for IPL I.

The parameters of the grad $H_{\parallel}$ -distribution on IPL III were notable for

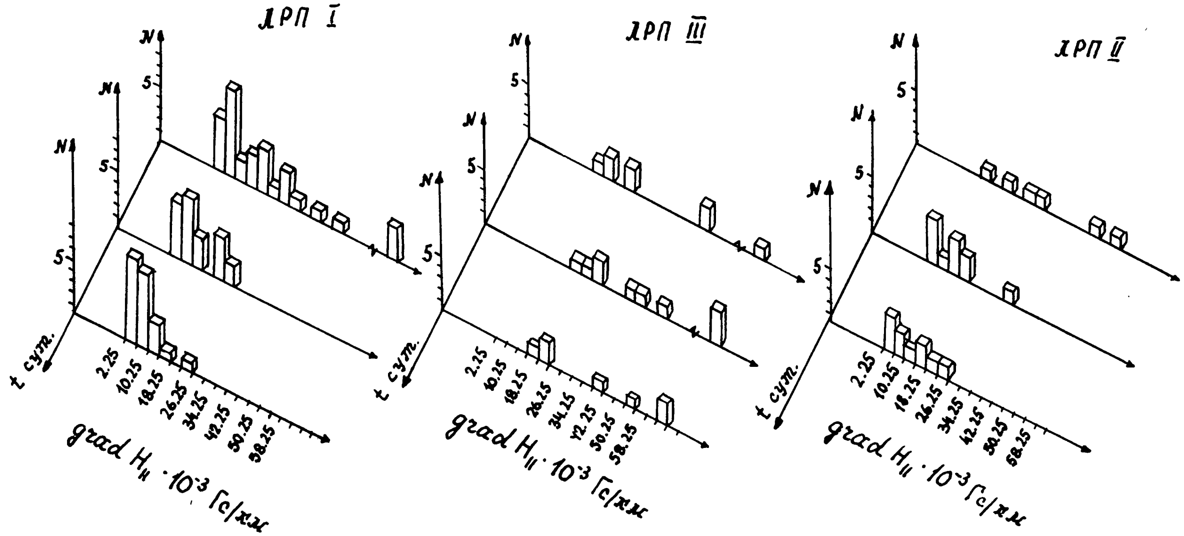


Fig. 3: The grad $H_{\parallel}$ -distribution histogram along IPL - Inversion Polarity Lines Nos. I - III.

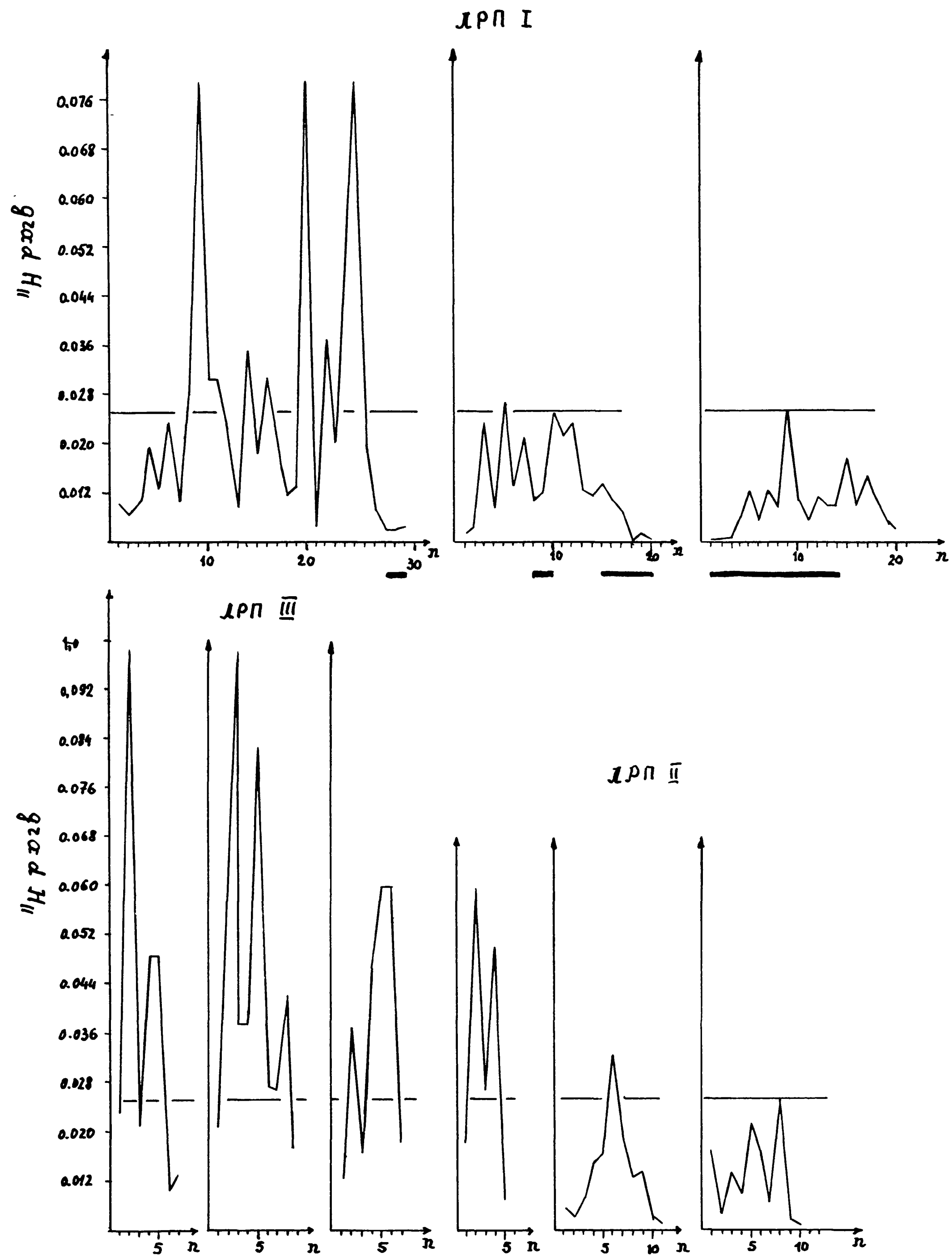


**Fig. 4: grad $H_{\parallel}$ behaviour along IPL I-III- A heavy lower line marks the filament location.**

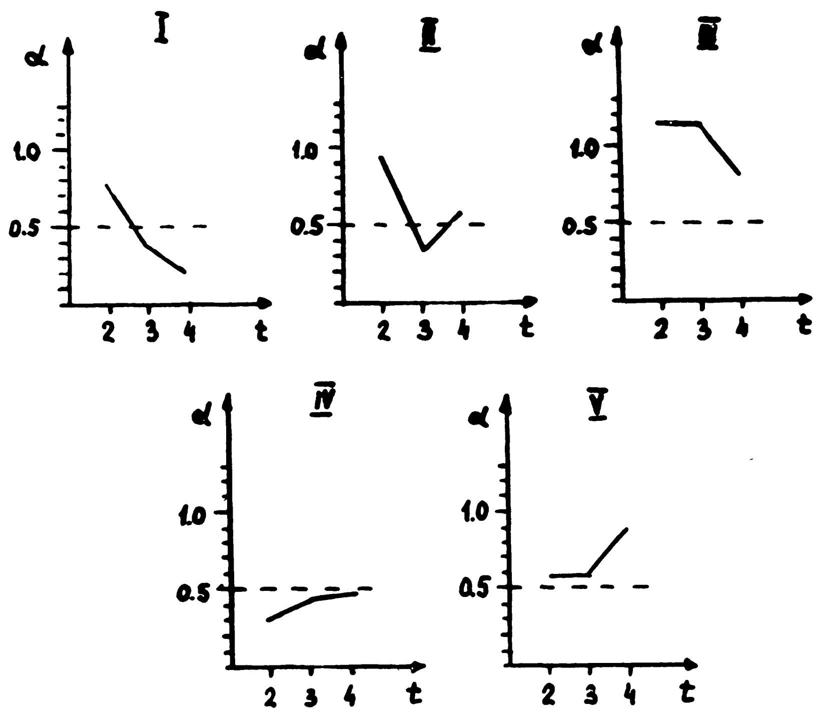


Fig. 5: Time behaviour of the IPL nonuniformity coefficient vs m.f.

substantionally higher values as compared with IPL I. This IPL did not show any filament present. IPL V had a short length, namely about four times less than that of IPL I. The grad $H_{\parallel}$ values are close in magnitude to mean values of the IPL I gradient for 3 and 4 September while the values of $\delta$ are only slightly higher. From 1 to 7 September no filament was observaed along IPL V.

On 2 September IPL II showed large values of $\delta$ and $\langle$grad $H_{\parallel}\rangle$ but they decreased substantially by 4 September and became close in magnitude to the parameters of the grad $H_{\parallel}$ -distribution on IPL I. Yet no filament occurred along that line aither on that day or on the next. Only on 6 and 7 September we observed the penetration of the westward end of the filament lying on IPL IV inward a young active region, now along IPL II.

Thus, the form of the histogram of the grad $H_{\parallel}$ -distribution along the IPL and its time evolution provide insights into the filament occurrence probability along a given IPL or along separate segments of it.

However, the histograms do not reflect the fact that an IPL may be severely nonuniform with regard to the magnetic field. This is illustrates by Figure 4 which gives the grad $H_{\parallel}$ values measured consecutively along IPL I-III. To ease the interpretation, the IPL are drawn as straight lines, with the section separations assumed equal. Therefore, it seems appropriate to attempt to introduce some numerical parameter characterizing the nonuniformity of the grad $H_{\parallel}$ -distribution along zhe IPL:

$$\alpha = \frac{\sum_{i=1}^{k} \beta_i + 2\gamma}{n + 2} \qquad (1)$$

Here n is the number of measurements, k is the number of extrema on the smoothed-out plot of grad $H_{\parallel}$ -values, and $\beta_i$ is the weight coefficient of the i-th maximum, defined as

$$\beta_i = \begin{cases} 1 & \text{for grad } H_{\parallel} i \leqslant \text{grad } H_{\parallel}^{max} , \\ \dfrac{\text{grad } H_{\parallel} i}{\text{grad } H_{\parallel} max} & \text{for grad } H_{\parallel} i > \text{grad } H_{\parallel}^{max} , \end{cases}$$

where grad $H^{max}$ is the maximum value of grad $H_{\parallel}$ , measured on a segment of the IPL with the existing filament (in our case 0.0231 Gs $km^{-1}$ ). All minima on the plot were taken to have a weight equal to 1; also, the numerator of formula (1) incorporates the coefficient $\gamma$ that implies that where the IPL terminates, the conditions for the existence of a filament there are no longer satisfied. We have ascribed to this coefficient the value of 1 and the calculated values of are presented in Figure 5.

From Figure 5 it is apparent that the parameter $\alpha$ describes quite reasonably the situation along IPL I and III-V, viz. the small values of $\alpha$ correspond to the existence of a filament (IPL I and IV) and, vice versa, the large values of $\alpha$ indicate there is no filament present (IPL III and V). A more complicated situation is observed along IPL II. On 3 September the underlying magnetic field in the vicinity of this line favours the appearance of a filament and, particularly, not only in the parameter $\alpha$ but also in $\langle$grad $H_{\parallel}$ $\rangle$ and $\delta$. Nonetheless, no filament occurred during those days. This discrepancy seems to imply the fact, already emphasize in (1), that the presence of sufficiently extended portions with low values of grad $H_{\parallel}$ along the IPL is a necessary but not a sufficient condition for the formation of a filament. This is, possibly, accounted for by the fact that the parameter $\alpha$ is not appropriate to describe the behaviour of the magnetic field at heights where the filament is formed (for example, "flattening" of the tops of arches in the Pikel'ner /5/ model). Possibly, this could be allowed for indirectly by introducing a parameter that describes the age of an active region; however, further investigation is needed toward this end.

Thus, the study carried out in this paper suggests the following conclusions.

1. On the basis of the longitudinal magnetic field gradient distribution in the vicinity of the inversion polarity line it is possible with reasonable confidence to judge about the presence or absence of a filament along this line.

2. In addition to the existence of an inversion polarity line, the nece-

ssary conditions for filament occurrence in an active region are: a bias of the grad $H_{\parallel}$ -distribution toward lower gradients and the presence along the inversion polarity line of rather extended portions, uniform with respect to the magnetic field, which have values of grad $H_{\parallel}$ not exceeding a certain limiting value.

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## DISCUSSION

Могилевский М.А.

Может-ли ток в волокне изменить распределение $H_{\parallel}$ на уровнефотосферы ?

Максимов В.П.

Нет, по- видимому, ток во волокне не может изменить распределение $H_{\parallel}$ на уровне фотосферы. Но, вследствие положительной обратной связи, он может вызвать некоторое продвижение волокна в область большего grad $H_{\parallel}$ вблизи линии раздела полярностей.

V. Bumba

Вы измеряете Ваши градиенты перпендикулярно границе полярностей. Но, отдельные волоконца волокон идут обыкновенно параллельно границе полярностей и только их "ноги" связаны с магнитными полями противоположной полярности. Это можно наблюдать даже при очень больших градиентах поля (группа июнь/июль 1974 г.). В этом случае Вами измеряемые градиенты играют наверно только роль определенных параметров характеризирующие магнитное поле.

Максимов В.П.

Закрепление оснований силовых линий, поддерживающих волокно, на границах супергранул скорее относиться к большим волокнам вне активных областей. На $H_{\alpha}$-фильтрограммах с разрешением 2-3" мы этих оснований не видим. Поэтому мы выбрали принцип измерений grad $H_{\parallel}$ по линии, перпендикулярной линии раздела полярностей. Эсли мы совершаем при этом ошибку, то каждый раз делаем ее одинаково.

Буров В.А.

Какова ошибка измерений ?

Максимов В.П.

Ошибка измерений составляла $\pm$ 0,0001 Гс/км.