MAGNETIC SHEAR IN FLARING REGIONS

I. *Quantitative Evaluation of the Change in Shear*

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Abstract. We have evaluated the shear angle of the neutral line of the non-potential magnetic field for one or two days prior to and after the flare event for 10 cases. We have used the Hα filament positions to evaluate the shear in the neutral line. We find from the samples we have studied that it is the change in the shear that occurs a day prior to the flare that can lead to the event. This change can be in either direction, i.e., it can be a large increase from a small value or a decrease from a large initial value. Thus it is the change in the shear angle that seems to be a deciding criterion for a flare to occur and not a large value for the shear angle itself. We have one instance where there was no significant change in the shear angle over a period of a few days and this region, although similar to other active regions studied, did not produce any flare activity.

1. Introduction

It is currently believed that the primary source of energy released in solar flares is the free energy stored in stressed magnetic fields. The increasing deformation of the magnetic loops from a potential configuration provides the reservoir for the storage of this excess free energy. Recent morphological studies of potentially active regions have shown that the deformation of magnetic field lines is caused by the relative motion of sunspots (which form the footpoints of the loops) and there is evidence to infer that flares occur in the transition from the sheared configuration to the potential field configuration (Zirin and Tanaka, 1973; Neidig, 1979). Tanaka and Nakagawa (1973) and Ambastha and Bhatnagar (1988) have shown that proper motions of sunspot pairs can cause the energy build up and also provide the right amount of energy involved in flaring. The reorientations among the spots of different magnetic polarities cause shearing of the interconnecting fields and consequent build up of energy in this process.

Vector magnetic field measurements in the photosphere provide direct evidence for the twisted or sheared nature of magnetic loops. In the absence of such measurements, the sheared configuration can be inferred from the Hα filaments, which assume the neutral line position dictated by the sheared magnetic loops. The sheared magnetic field is defined as a non-potential field ($\mathbf{J} \times \mathbf{B} = 0$) which is caused by shear flows in the photosphere. A quantitative measure for the magnetic shear at the photospheric level was proposed by Hagyard *et al.* (1984) from a detailed study of one active region. They defined the 'degree of shear' as the angle in azimuth between the directions of the observed magnetic field and of the potential field. Their analysis shows that the angle of shear assumed as large a value as 85° when the flare occurred in that active region. Thus although the studies have led to the belief that the presence of shear is a necessary

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condition for a flare to occur, it is not known at this stage whether there is any threshold value for this angle which will trigger the flare, nor whether a large value of shear is a prerequisite to lead to a flare. To answer some of these questions, a programme was initiated in late 1988 by two of us (KRS and SMA) at Kodaikanal, whereby several sequences of photographs (photoheliograms and Hα spectroheliograms) were acquired on as many days as possible. From this material we have examined the evolution of active regions and derived the angle of shear for several cases using the sunspot positions and the Hα filament configuration as diagnostic tools to infer the shear. In most of the cases the large material permitted constant monitoring of the angle of shear both prior to and after the flare. We find that it is the change in the shear angle during the day prior to the flare that could be considered as the forerunner criterion and not the actual (not necessarily a large value) of the shear. Also there are indications from our study that larger changes in shear can result in flares of greater importance.

2. Data and Method of Reduction

The programme of acquiring sequences of photoheliograms and spectroheliograms in Hα during the solar maximum period for this scientific programme was started in late 1988, with the intention of collecting as many sequences as possible. These observations are essentially extensions of the synoptic observation programme of the Sun at Kodaikanal in vogue since 1907, which consists of photoheliograms and spectroheliograms in Hα and Ca II K_{232} normally once a day. For our present programme, we obtained photoheliograms once every 60 min or at times every 30 min with additional Hα spectroheliograms wherever possible and necessary. The solar image has a diameter of 200 mm on the photoheliograms and about 60 mm on the spectroheliograms. For every case we have studied here, we adopted the following data reduction procedure to derive the angle of shear. Now, the angle of shear at any point at the photospheric level is the angle in azimuth between the directions of the potential field and of the total field at that point. We have used the argument that the value of the shear can be derived from the Hα dark filament which assumes the azimuth of the neutral line of the non-potential field. We picked out for each case the photoheliogram and spectroheliogram as close to the time of occurrence of the flare as possible. This formed a photoheliogram – spectroheliogram (PHG – SHG) pair for further reduction work. We enlarged the SHG image ($\sim$ 60 mm diameter) and projected it (through an enlarger) onto the photographic print of its PHG mate and aligned them for a perfect match using the (N–S) and equator (E–W) pole markings. We then sketched the position of the Hα filament on the PHG print.

In addition, we also picked out at least one such PHG–SHG pair for the day prior to the flare (and wherever possible for 2 days prior to the flare) and one day after the day of the flare. For these cases also we sketched the positions of Hα filaments in the same way on the PHG prints. Now to measure the shear angle we proceed as follows. We have chosen as X-axis the line joining the centre of one sunspot to the centre of the other spot of the bipolar group. It has been possible to define the centres of the spots precisely in the cases we have studied. In instances of more complicated distribution of spots, the method of Teuber, Tandberg-Hanssen, and Hagyard (1977) would be called for to compute the potential field. We have chosen the point of intersection of the neutral line (Hα filament) and the X-axis as the origin of the coordinate system and the Y-axis to be orthogonal to the X-axis. Now, the shear angle γ is the angle between the Y-axis and the neutral line (i.e., the Hα filament).

Most of the regions chosen for the present study are within 45° from the central meridian. However, for the two (NOAA 6022 and NOAA 5969) extreme cases where the longitude positions reach this limit, we have converted both the sunspot positions and the position of the Hα filament, where the shear angle was measured to the heliographic coordinates, as test cases. We find the conversion to heliographic coordinates for these cases did not alter the value of the shear angle significantly and hence for the remaining cases the change could be still smaller, one exception being NOAA 5900 which was observed while at 80 °W.

3. Results and Discussions

The angles of shear γ, derived as described above for the cases studied by us, are presented in Table I. It can be seen from column 10 of Table I that flares occur in those cases where the change in the shear angle is 15° or more. We have presented the shear angle vs day in Figure 1, which illustrates these points better. Our present data would, however, permit us only to set an upper limit (i.e., one day) for the temporal change in shear, whereas it would be worthwhile to examine whether changes in the shear angle seen in our data really occur within a few hours preceding the flare event or are they spread over a larger span of time. Another point that should be noted is that this change in the shear angle leading to the flare can be in either direction, i.e., the change can either result in an increase or decrease in the shear angle. This establishes that it is not the absolute value of the shear angle that matters, but the change in the shear angle (and more possibly the rate of change) that is important in deciding the occurrence or non occurrence of the flare event. The case of the active region of April 4–9, 1989 (NOAA 5428) would be of special interest since it provides an example where a flare did not occur as the shear change was not significant enough, although the spot had the same common characteristics (like area) as other cases presented in Table I. It is also evident that the greater the change in the shear (or the rate of change in the shear) the brighter the flare in Hα. It is obvious from Figure 1 that the shear, soon after the flare, tends to recover to its preflare value.

We have used the Hα filament as the proxy for the neutral line of the non potential field, whereas Hagyard *et al.* (1984) used the observed total field itself to derive the angle of shear. It is not established at this stage whether the shears derived from the vector magnetograms are numerically the same as the shears derived using the Hα filament, i.e., whether the gross similarity at the macroscopic level between the photospheric and the chromospheric features can be assumed to hold good for the angle of shear also. Although intuitively a numerical agreement cannot be expected, we are investigating this

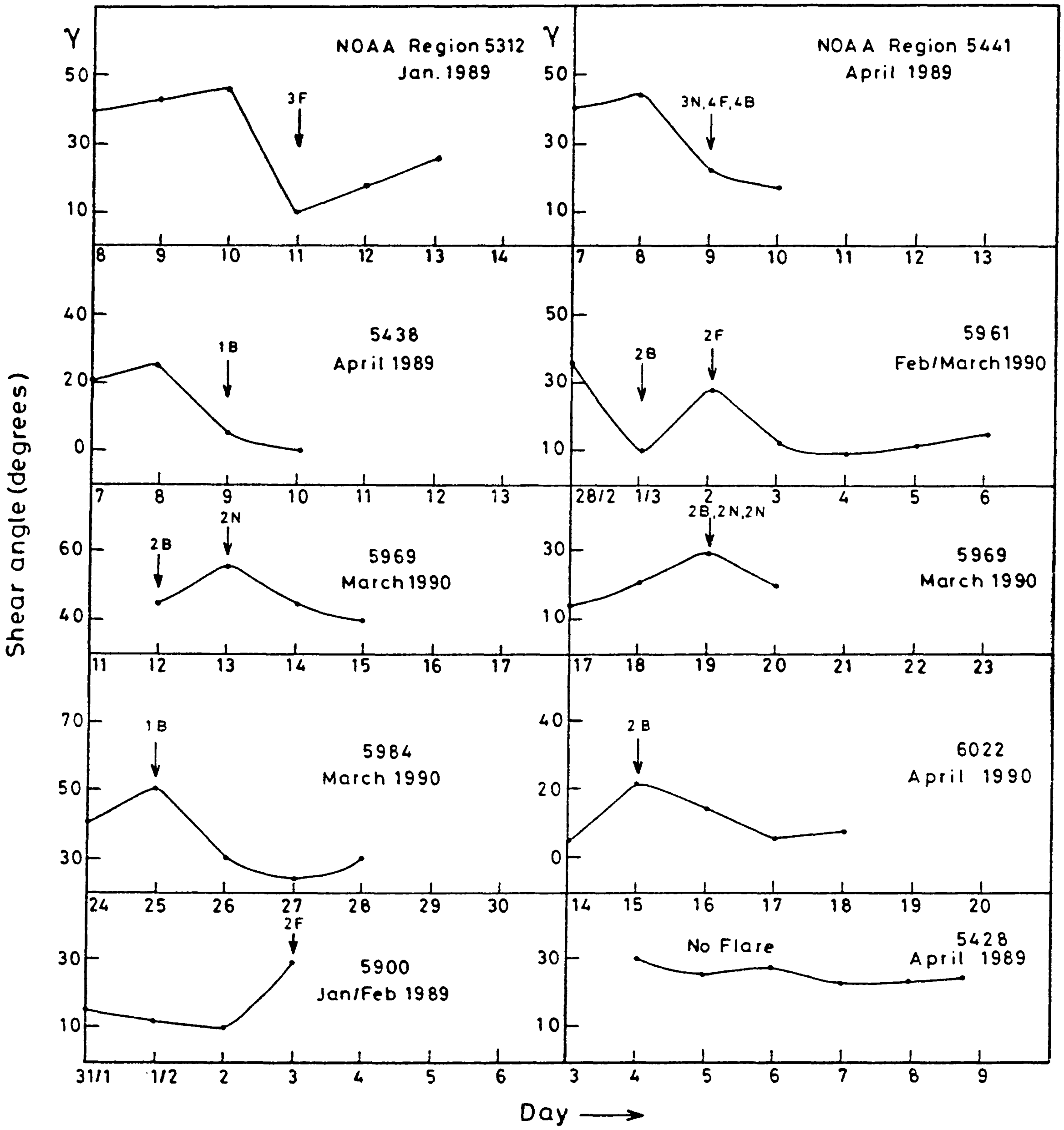

Fig. 1. Plot of the shear angle γ in degrees vs the day. The shear is the angle in azimuth between the direction of the potential field and the neutral line (which is the Hα filament in the present study). Notice that a flare occurs whenever there is a large change in γ ($> 15°$) in either direction. Also, after the flare, the shear tends to recover to the preflare value. For details about the NOAA regions see Table I.

point and a communication will follow. But one decided advantage with the use of Hα filaments would be that the measured shear pertains to the chromospheric level, and conventionally the importance of flares is also based on the brightenings (Hα) at this level.

Although it is believed that solar flares are related and sequel to the relaxation of force-free magnetic fields, it is not known presently at what stage in the shear change do the plasma instabilities set in leading to the flare event. In the absence of enough data to answer this question, the change of shear as studied by us here provides probably the best information that can be derived presently.

TABLE I

Details for each event. Information in columns 3, 4, 7, and 8 were extracted from the respective issues of the *Solar Geophysical Data* (comprehensive reports). PHG – Kodaikanal photoheliogram. SHG – Kodaikanal spectroheliogram.

Seq. No.	Date	NOAA region	Location	Spot area (10^{-6} disk)	Flare area (10^{-6} disk)	Hα flare			Imp.		Mean epoch of		Shear angle
						start (UT)	max (UT)	end (UT)	opt.	X-ray	PHG UT	SHG UT	
1	2	3	4	5	6	7			8		9		10
1	January 1989												
	8		S 32 E 67								05:05	06:09	40°
	9		No observation										
	10		S 32 E41	1588							04:45	04:15:15	46°
	11	5312	S 32 E28	1955	1020	06:36	06:49	07:10	3F	M1.9	04:50	06:04:29	10°
	12		S 33 E15	1621							04:46	06:00:05	18°
	13		S 33 E02	1274							02:25	02:37:45	26°
2	April 1989												
	7		N 35 E 49	344							03:15	03:07:45	41°
	8		N 35 E 36	273							02:01	02:26:55	45°
	9	5441	N 35 E 28		1247	00:44	00:54	02:36	3N	X3.5	01:55	02:06:08	22°
		5441	N 34 E 29	531	3333	00:44	00:53	02:29	4F				
		5441	N 35 E 29		979	00:44	00:59	02:39	4B				
	10		N 35 E 13	385							02:27	02:17:25	17°
3	April 1989												
	7		S 16 E30	144							03:15	03:07:45	21°
	8		S 16 E17	166							02:01	02:26:55	25°
	9	5438	S 20 E05	128	482	02:00	02:06	02:33	1B	M1.6	01:55	02:06:08	5°
	10		S 16 W11	127							02:27	02:17:25	0°

Table I (continued)

Seq. No.	Date	NOAA region	Location	Spot area (10^{-6} disk)	Flare area (10^{-6} disk)	Hα flare			Imp.		Mean epoch of		Shear angle
						start (UT)	max (UT)	end (UT)	opt.	X-ray	PHG UT	SHG UT	
1	2	3	4	5	6	7			8		9		10
4	Feb./March 1990												
	February 28		N 32 E 50	932							04:10	02:29:36	35°
	March 1	5961	N 30 E 38	881	308	03:39	03:40	04:18	2B		03:42	02:59	10°
			N 30 E 39		237	03:39	03:40	04:30	1B				
	2	5961	N 30 E 23	550	349	00:59	01:18	02:53	2F		02:10	02:20	28°
	3		N 32 E 09	556							02:25	03:26	12°
	4		N 32 W 04	482							03:00	02:44	9°
	5		N 31 W 15	336							02:10	02:12	11°
	6		N 31 W 28	225							02:12	03:20	15°
5	March 1990												
	12	5969	N 31 E 55	500	294	00:51	00:58	01:08	2B		02:10	03:01	45°
	13	5969	N 32 E 40	609	293	02:43	02:43	02:49	2N		02:15	02:14	56°
		5969	N 31 E 38			07:24		08:16	1B				
	14		N 33 E 25	550							02:00	02:53	45°
	15		N 33 E 12	564							02:15	03:40	40°
6	March 1990												
	17		N 32 W 14	513							02:12	03:00	14°
	18		N 32 W 27	639							02:00	02:58	21°
	19	5969	N 32 W 40			04:38	04:42	06:38	1B				
		5969	N 32 W 40			04:38	05:43	06:38	1B	X1.5			
		5969	N 34 W 40	516		04:40	04:57	06:12	2B		01:50	02:51	30°
		5969	N 32 W 40			05:07	05:10	06:41	2N				
		5969	N 35 W 38			06:16		07:16	2N				
	20		N 32 W 53	500							02:15	02:07	20°

Table I (continued)

Seq. No.	Date	NOAA region	Location	Spot area (10^{-6} disk)	Flare area (10^{-6} disk)	Hα flare			Imp.		Mean epoch of		Shear angle
						start (UT)	max (UT)	end (UT)	opt.	X-ray	PHG UT	SHG UT	
1	2	3	4	5	6	7			8		9		10
7	March 1990												
	24		S 13 S 06	568							04:25	04:32	40°
	25	5984	S 12 W 20	897	235	04:10	04:25	05:03	1B		04:45	05:55:39	50°
	26		S 14 W 35	1044							01:55	03:04	30°
	27		S 14 W 47	1191							02:40	05:12	24°
	28		S 14 W 59	1198							03:25	03:21	30°
8	April 1990												
	14		N 32 E 70	1820							02:00	03:14	5°
	15	6022	N 30 E 50	1790	525	03:09	03:09	05:26	2B	X1.4	02:00	03:30	22°
	16		N 33 E 40	1458							02:45	03:26:45	14°
	17		N 33 E 22	1263							06:35	06:10	6°
	18		N 33 E 13	1110							02:12	03:04	8°
9	Jan./Feb. 1990												
	January 31		S 12 W 45	1152							04:10	04:19:49	15°
	February 1		S 13 W 60	1625							01:55	03:15:40	12°
	2		S 12 W 70	1168							02:05	02:02	10°
	3	5900	S 13 W 81		257	01:09	01:09	01:24	2F	M6.9	02:10	02:13	30°
	4	Spot has reached the limb. Measurement very uncertain.											
10	April 1989												
	4	5428	S 18 E 13	1465	No flare						01:58	02:45:48	30°
	5		S 18 W 01	1407							02:13	02:09:38	26°
	6		S 18 W 14	1030							01:58	02:43:54	28°
	7		S 18 W 27	1345							03:15	03:07	23°
	8		S 18 W 40	1045							02:01	02:41:55	24°
	9		S 18 W 52	1016							01:55	02:41:35	25°

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