FIVE-MINUTE OSCILLATIONS IN THE SOLAR MAGNETIC FIELD

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Abstract. Evidence for the existence of 5 min oscillations in the photospheric and low chromospheric magnetic fields is presented, their properties discussed, and a possible production mechanism suggested.

For about a decade it has been known that there are velocity oscillations in the photosphere and low chromosphere with periods of about 5 min (Leighton *et al.*, 1962). These oscillations have also been detected in the brightness, both in the wings of lines, and in the continuum.

A logical question which follows from this is whether or not these oscillations are present in the magnetic field as well. In this paper we report the answer as – yes, they are there, but are often well hidden by the noise.

In 1967, Severny reported seeing oscillations in the magnetic field, but these were of periods seven to nine minutes rather than five minutes, and somewhat irregular.

The simplest way to look for oscillations in the magnetic field is to use the solar magnetograph to observe a single point on the Sun for several hours, scanning westward very slowly to compensate for solar rotation. The raw data for this type of observation consists of the velocity as a function of time, the magnetic field as a function of time, and the brightness as a function of time. In Figure 1 the velocity and magnetic field are shown for one 3-hr observation of this type. All the observations discussed in this paper are of this 'non-scanning' type.

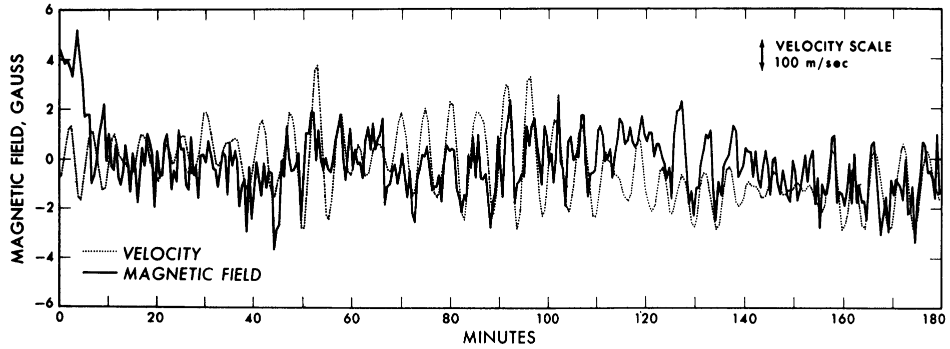

Fig. 1. Plot of velocity and magnetic field as a function of time for an observation in which the aperture was fixed on a single point on the Sun, moving slowly westward across the disk to compensate for solar rotation. The oscillations in the magnetic field can be seen here.

Howard (ed.), Solar Magnetic Fields, 348–355.

The velocity curve of Figure 1 shows the 5 min oscillations are sometimes present and sometimes not present, as usual. Although the magnetic signal is very noisy, if one looks carefully one can see numerous cycles where the maximum in velocity coincides with the maximum in field, and where the minimum in velocity coincides with the minimum in field.

Figure 2 is an autocorrelation of the magnetic field for four separate observations of the type just described. The four runs were scattered over a period of two years. Each of the observations was for an interval of about three hours. The top one is for the data

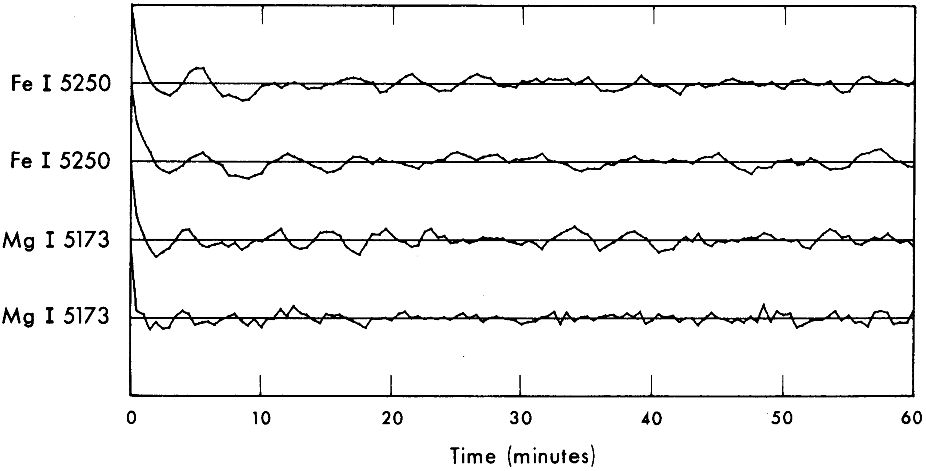

Fig. 2. Autocorrelation of magnetic field for four separate observations. The horizontal line passing through each curve represents a correlation of 0. The lines above and below represent + 1.0 and − 1.0 respectively.

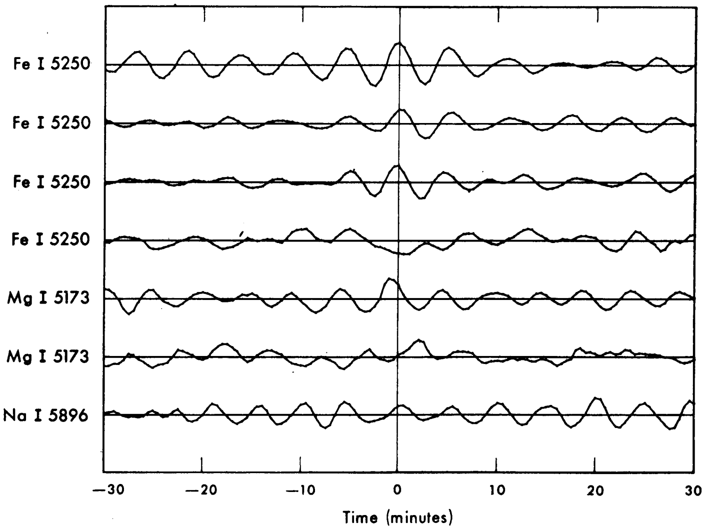

Fig. 3. Cross correlation of velocity and magnetic field. Same scale as Figure 2.

of Figure 1. Two are for the photospheric line Fe I 5250 and two for the low chromospheric line Mg I 5173. The maximum for the two iron runs occurs at just over 5 min, while the maximum for the magnesium runs is about forty seconds less. This is consistent with the well known fact that the period decreases somewhat with height (Noyes and Leighton, 1963).

Figure 3 shows a cross correlation between the magnetic field and velocity for several spectral lines. Note that all the curves are oscillatory in character for several cycles. This means that *both* the velocity and magnetic field have the oscillations because the cross correlation of a sine wave (velocity) with random noise (magnetic field) is essentially constant at zero. If one curve is random noise, it does not matter how much you shift it with respect to the other one, the correlation is the same.

Note that the fourth curve has an *anti*correlation at zero lag. This is just due to the fact that if the sign of the field is reversed, the sign of the correlation coefficient will reverse, but of course the physical interpretation is the same. In other words, in a region of positive field the correlation coefficient is positive when the velocity and field are in phase, but in a negative field region there is an anticorrelation if they are in phase.

Another approach to digging the magnetic field oscillations out of the noise is to use a superposed epoch analysis. First the velocity and magnetic field are plotted as functions of time. Then the starting time of the individual velocity oscillations are determined. Then, conceptually at least, the individual velocity oscillations are cut out and pasted vertically below one another. The same thing is done for the magnetic field (or brightness) but with the starting times determined from the *velocity* observations. In Figure 4 and 5 the first column is velocity, the middle column is magnetic field, and the last column is brightness. One thing that is immediately obvious is that the magnetic signal is very noisy.

The top magnetic curve corresponds to the same time interval as the top velocity curve. The second magnetic curve corresponds to the same time interval as the second velocity curve, etc. At the bottom of the first column is the average velocity oscillation. Next to it is the average magnetic field during a velocity oscillation. Next to that is the average brightness during a velocity oscillation. The magnetic signal is still rather noisy, not surprising considering what went in to it, so a 30 s running mean was computed and is displayed at the bottom of each column. Here the 5 min oscillation in the magnetic field shows up quite clearly. Remember that the time intervals were chosen so as to line up the velocity curves in phase; the fact that the oscillation comes through in the field means that there is a definite phase relation between the two.

Figure 6 is a summary of four superposed epoch analyses. The example in the lower left hand corner looks like it is out of phase with the others, but that is just because it is in a region whose field polarity is opposite to those of the other three examples, so it is really not shifted by 180°. The graph in the lower right hand corner seems to have the magnetic phase advanced somewhat. This is for the magnesium line. The brightness oscillations in the chromospheric lines are advanced with respect to the photospheric lines, so this may be related in some way.

The observational results may be summarized as follows:

(1) Using three techniques (namely, looking at the raw data, correlation analysis, and superposed epoch analysis) the existence of periodic oscillations in the Sun's magnetic field has been demonstrated.

(2) The periods are the same order as the velocity periods, about 5 min.

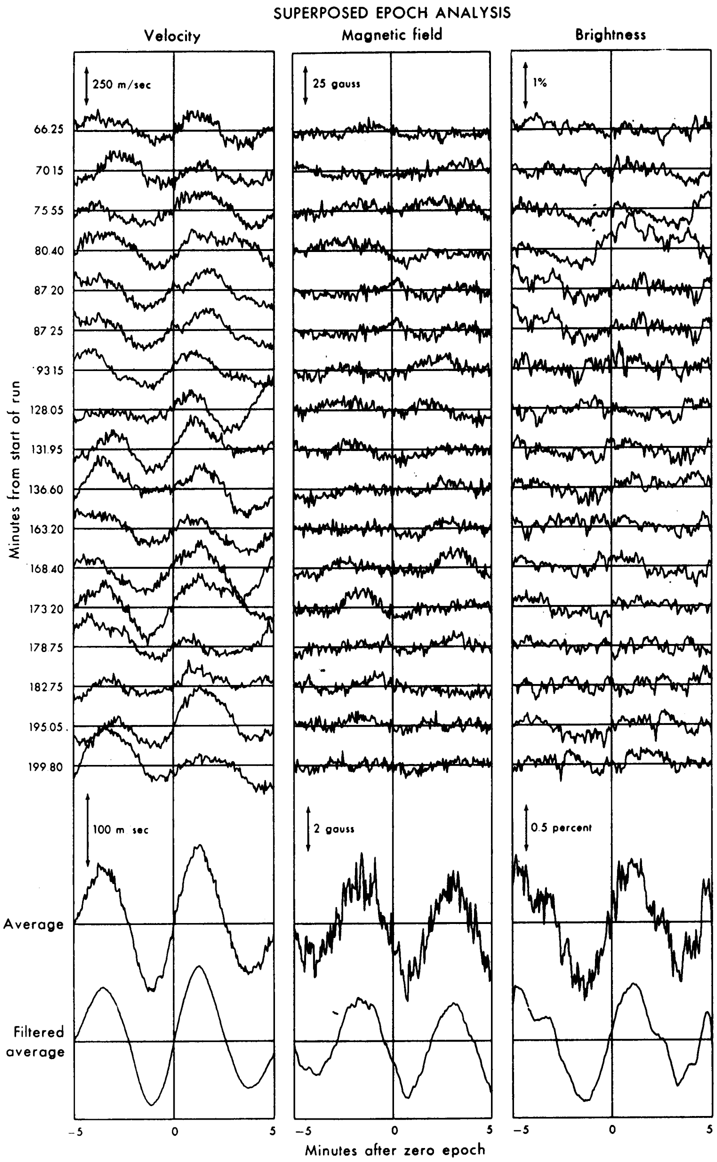

Fig. 4. Superposed epoch analysis of an observation of the type shown in Figure 1. The curves labeled 'average' represent the average of all the curves above them, although at a different scale. The filtered average is a 30 s running mean of the average to remove high frequency noise.

(3) The magnetic oscillations have a definite phase relation with the velocity oscillations.

(4) They exist at least over the range in height covered by the lines Fe I 5250 to Mg I 5173.

(5) The amplitude is around one or two gauss; consequently they can be easily masked by noise.

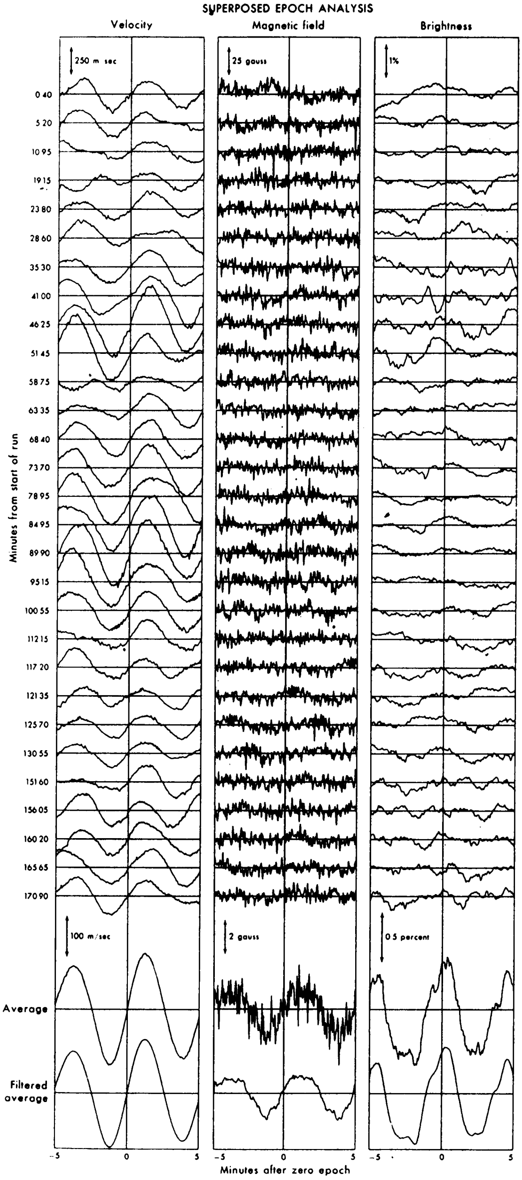

Fig. 5. Same as Figure 4, but for different observations.

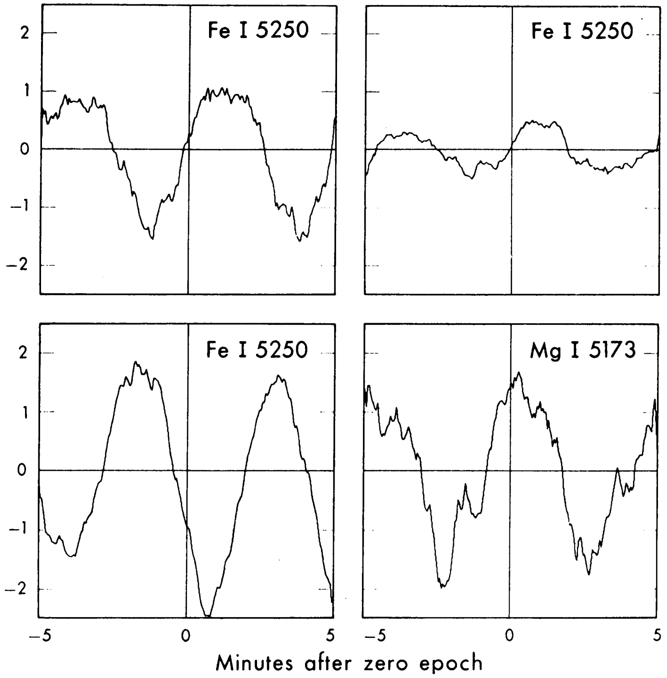

Fig. 6. Four examples of mean magnetic field oscillation profiles during a velocity oscillation as deduced from superposed epoch analysis.

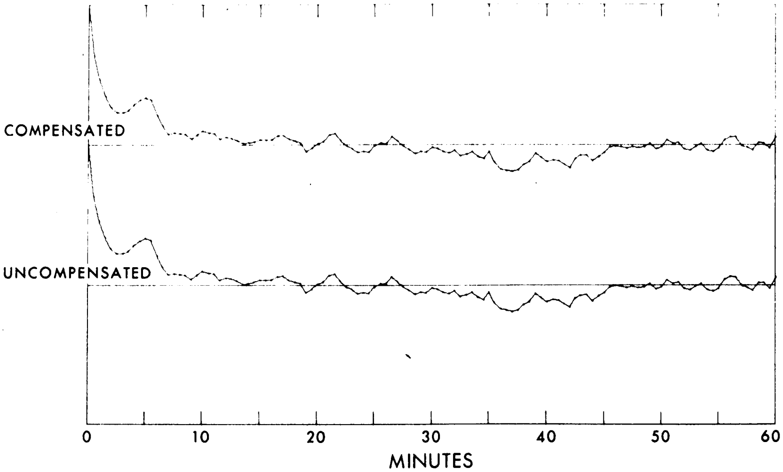

Fig. 7. Upper curve is autocorrelation of magnetic field as normally computed (Zeeman signal divided by brightness signal). Lower curve is for the same data but without compensation for brightness variations, i.e. just the Zeeman signal. The similarity of the two curves shows that the 5 min oscillations in the magnetic field is not a feed through of the brightness oscillation.

(6) They occur both in regions of weak field (<5 G) and in regions of strong field (≈ 80 G).

Now that it has been established that the 5 min oscillations exist in the magnetic field, the question of what causes them arises. One possibility is some instrumental artifact. Inasmuch as the oscillations are present in both the velocity and the brightness they might be feeding through into the magnetic field observations.

First consider the brightness. The brightness oscillations in the photosphere consist of a 1% variation in the average light level, so it is a very small effect. The magnetograph does not actually record the magnetic signal, but rather the Zeeman signal, which is proportional to the product of the magnetic field and the brightness. To get the magnetic field, a computer program divides each Zeeman reading by the instantaneous value of the brightness, so the oscillations in the brightness cancel out exactly. As a check, an autocorrelation was made both with and without this brightness compensation. Figure 7 shows the 5 min peak present in both cases.

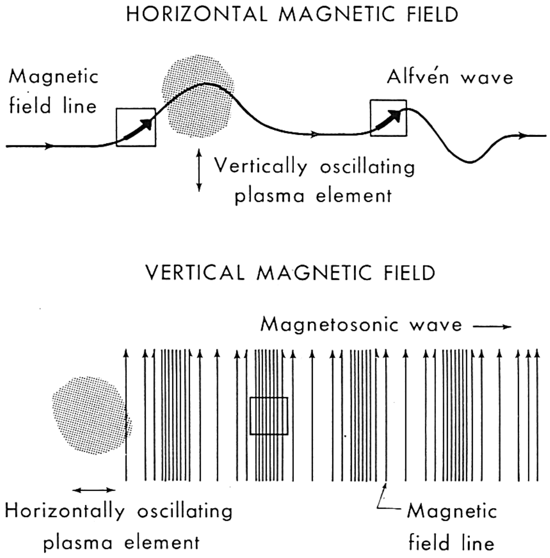

Fig. 8. Schematic representation of how oscillations in the solar plasma could be transferred to the line-of-sight magnetic field. If the magnetograph aperture coincided with any of the small squares, the magnetic field would show an oscillatory character. In the top example, the magnetic field oscillations would have an average of zero gauss; in the bottom example, the average would be non-zero.

Now consider the velocity. It is true that the spectral line is moving back and forth with a period of five minutes, but the magnetic signal is accoupled to the velocity; it depends only upon changes in the line profile occurring at the KDP frequency, which is 18000 times higher than the frequency of the velocity oscillations. In addition, it is hard to explain how an instrumental effect would appear both in the weak field case where the Zeeman signal changes sign, and in the strong field case where it does not. Furthermore, if it really were an instrumental effect, the phase shift between velocity and field ought to be constant, whereas in Figure 6 one of the examples has an appreciably different phase shift from the others.

If it is not an instrumental effect, it must be of solar origin. Because the solar magnetic field is frozen into the oscillating plasma, there are several ways in which the oscillations in the plasma (which are observed as velocity oscillations) could be transferred to the magnetic field. Figure 8 shows schematically how vertical waves could cause oscillations in a horizontal magnetic field, and how horizontal waves could cause oscillations in a vertical magnetic field.

Acknowledgements

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Discussion

Musman: You don't need MHD waves to produce oscillations in the magnetic field due to frozen-in field.

Tanenbaum: If a horizontal field is uniformly moved up and down there will be no oscillations in the longitudinal field, but if there are spatial variations there may be. That is what I intended to show in the last slide.