DIFFERENTIAL ROTATION AND THE SPOT ZONES*

(Research Note)

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Abstract. A minimum of angular velocity is not found at the equator as suggested by Gilman, but at a latitude of 6° in both hemispheres.

From numerical model calculations of the thermal convection in a Boussinesq fluid Gilman (1972) has predicted an equatorial deceleration of the solar differential rotation. We have tried to check this result with spectrographic observations and accordingly looked for maxima of the rotational velocity near the 10°–15° latitude belts in particular. Although we were not able to confirm Gilman's results, our observations seem to reveal a new fundamental feature of the solar differential rotation.

Until recently little attention has been paid by most spectrographic observers to the latitudinal fine structure of the differential rotation. Due to the large scatter of the average values (arising from a number of solar effects, like 5-min oscillations, supergranulation, and giant convective cells) usually the results were presented as fourth order polynomials or smooth curves otherwise, as already pointed out by Gilman (1972). On the contrary we devised our observations to yield the best resolution possible and also to be as 'differential' as possible in latitude.

The observations were carried out with the Doppler compensators of the Capri magnetograph (Deubner and Liedler, 1969) in October, 1974. The position of the lines C I 5380.32 and Fe I 5364.88 were recorded simultaneously on two independent channels. The observations at the east limb consisted of continuous scans with a 5° × 5° aperture tracing alternately the two long sides of a 696 Mm × 18.5 Mm rectangle centered parallel to the solar axis at a fixed distance of 0.8 $R_\odot$ from the disk centre. The positions of the line shifters were recorded at 150 4.65 Mm intervals. The scanning cycle was repeated every 2.2 min for a total of 4 hr and 23 min on October 14.

At the west limb four more scan lines were added to form a six line raster scan filling the same area as before but providing a more rapid smoothing of the averages. A total observing time of 2 hr and 39 min was accumulated on October 16 and 17. The long duration of the observations served to average at each scanning point a sufficient number of 5-min oscillations as well as a large area on the solar surface extending at least beyond one supergranule radius.

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Reduction of the data included the following steps:

1. Averaging of the data at each one of the 150 different latitudes.
2. Smoothing by 17 point (79 Mm) running means.
3. Averaging of values at equal latitudes north and south of the equator.
4. Subtracting east and west limb data in order to remove the limb effect (θ dependence of photospheric line positions due to granular inhomogeneities).

The final results are shown in Figure 1. This figure has only a relative scale of angular velocities, since at the stage of planning this investigation it was not attempted to determine absolute values.

If the Sun would rotate like a rigid body the observed values should all lie on a straight line parallel to the abscissa. The effect of differential rotation can be seen easily and compared with previous observational results, plotted on the same scale.

A minimum of angular velocity is not found at the equator as suggested by Gilman (1972), instead a very pronounced minimum appears at a mean latitude of 6° in both hemispheres. This minimum is equally present at the eastern and western limb, and on the northern and southern hemisphere as well. We believe therefore, that this is a global feature of solar rotation.

A similar minimum was found in 1968 by Solonsky (1972) for photospheric lines at a latitude of about 25°. He reported on this deviation from a smooth differential rotation law, but he did not notice the very close coincidence of the angular velocity minimum with the actual latitude of the spot zones during the epoch of his spectrographic observations. It is probably not accidental that the minimum is now (1974) observed at 6° latitude, again in perfect coincidence with the actual position of the spot zones in either hemisphere. Since the velocity distribution observed is symmetric with reference to the equator, and, of course, antisymmetric across the central meridian, we can exclude the possibility that the effect is produced by line profile changes due to systematic temperature differences, radial velocities or magnetic fields occurring in the active latitude belts.

The residual effects caused by large scale velocity fields can be estimated from Figure 1 by comparing the results in the four quadrants of the disk. Sunspots were not present in the scanned areas. Only on October 16, the trailing part of MacMath region No. 13280 was cut by the scan line. Obviously this had no particular effect on the average velocity distribution in the NW quadrant either.

Preliminary analysis of a full disk Mt. Wilson tachogram for November 14, 1974 (Howard, private communication) also shows minima of differential rotation of the same order of magnitude at low latitudes in either hemisphere.

Although a physical explanation of the observed relation of the differential deceleration to the magnetic activity in the spot zones seems to be well possible, it is yet unclear, how the new findings can be reconciled with the work of Wilcox and Howard (1970), who found in agreement with the results of Newton and Nunn (1951) for magnetic features a significantly shorter rotation period than the one obtained from Doppler measurements by Howard and Harvey (1970).
Fig. 1. Doppler measurements of solar photospheric differential rotation. Measurements made at different phases of the solar cycle exhibit a velocity minimum at different latitudes. The inset displays the Fe I line results obtained in the four solar quadrants separately.

In order to substantiate our results more observations including a wider latitude belt and the determination of the absolute angular velocities should be continued well into the next solar cycle.

A reexamination of the Mt. Wilson data might also reveal the cycle dependent latitude fine structure of the differential rotation.
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