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The Observations of Hα, Fe II and He I in Classical Be Stars

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ABSTRACT We present a spectroscopic data of 19 classical Be stars in red region from λλ6340 to 6890 Å observed from 1 – 9 July 2007 at Bosscha Observatory Bandung, Indonesia. The studies were carried out on Hα λ6563Å, FeII λ6516Å and HeII λ6678Å lines profile. Based on Hα line profile the program stars can be classified into subgroups; Be-shell, Be and normal B stars. The correlation of equivalent width, eqw of HeII and spectral types clearly shows that early type stars have higher value than late type stars. The eqw and fwhm values for the lines under investigation show a slightly decreasing correlation upon rotational velocity, *V sin i*.

ABSTRAK Kami membentangkan data spektroskopi bagi 19 bintang Be klasik dalam kawasan merah dari λλ6340 hingga 6890 Å yang diambil dari 1 – 9 Julai 2007 di Balaicerap Bosscha, Bandung, Indonesia. Kajian dijalankan terhadap profil garisan Hα λ6563Å, FeII λ6516Å dan HeII λ6678Å. Berdasarkan profil garisan Hα, bintang - bintang program boleh dikelaskan kepada subkumpulan iaitu bintang Be-shell, Be dan Be normal. Perhubungan diantara lebar setara, eqw bagi HeII dan jenis spektrum menunjukkan bahawa bintang peringkat awal mempunyai nilai yang lebih tinggi berbanding bintang peringkat akhir. Nilai – nilai eqw dan fwhm bagi garisan – garisan yang dikaji menunjukkan hubungan penurunan yang sedikit terhadap halaju putaran, *V sin i*.

(**Keywords:** spectroscopy, Be phase, Be-shell phase, normal B phase, rotational velocity.)

INTRODUCTION

In stellar evolution, B type stars are categorized as early type and among the hot stars, whose spectrum normally show the absorption lines whereas Be stars are non-supergiant B type stars whose spectrum has or had at some time one or more Balmer lines in emission (Collin, 1987). It has been observed that the luminosity of this type of stars are in the luminosity class of III – V which are usually called classical Be stars (Jaschek et al, 1981). Other classification was made according to the spectral profile of Be stars in which the spectrum has been classified into two terms: the Be spectrum and Be shell spectrum. In the Be spectrum, emission lines show either no reversal or more or less central reversal, whereas in the Be shell spectrum, Balmer lines and singly ionized metal lines exhibit narrow and deep absorption cores, which may or may not be bordered by emission wings (Doazan,1982). According to Marlborough,J.M. (1976), Struve (1931) was the first to suggest that the emission lines arose from matter which were ejected from the equatorial region of a rapidly rotating star and that lead him to propose the classical model of the rotating envelope of Be stars and the types of Be stars emission-lines profiles which were classified into three types: 1) Pole-on stars – stars that are characterized by single-peaked narrow emission lines superimposed on the photospheric absorption lines, 2) Be stars (ordinary) – stars showing double-peaked emission lines profiles, and 3) Be-shell stars – stars with sharp and deep absorption components in the centers of double-peaked emission lines which usually includes the equator-on Be stars (Kogure, T. and Leung, K.C 2007). In optical region, most of the investigations were carried out on Balmer lines, mainly in Hα. Recent studies considered He and Fe lines as the kinematics of the circumstellar shell (Hanuschik, R.W. 1994, S mith, M.A., 1995). While Hα emission line occurs at large distance across the entire shell, the ringlike zones of HeI emission are situated relatively close to the central star. Thus, the strong HeI lines (5876Å and 6678Å) have an important diagnostic value for activity close to the star's surface (Pollmann, E., Leverkusen and Stober, B. 2007, Be Star Newsletter, Vol.38). In this paper, we present the spectral profiles of classical Be stars in which investigations were carried on in FeII λ6516, HeI λ6678 and Hα λ6563.

OBSERVATIONS

The observations of the 19 program stars including of B, Be and Be shell stars presented here were carried out for 6 nights (1 – 4 July 2007 and 8 – 9 July 2007) on the 60 cm Refractor telescope of Bosscha Observatory in Bandung, Indonesia. The observations were conducted using Bosscha Compact Spectrograph (BCS) and CCD camera as the detector. These were mounted at prime focus of the f/18 telescope. The dispersing element is a 1200 gr/mm which was set at β = 9.0 degrees and resolution of R ≈ 18,000. It gives a reciprocal dispersion of 0.350 Å/ pixel at the detector and a spectral coverage of about 535 Å per CCD frame which ranging from about λ6340 to λ6890Å. All the data have been obtained at -10˚C of the detector. The integration times were ranging from 300s to 1800s depends on the magnitude of the objects. Calibration on the wavelength scale on the detector was done using Fe-Ne lamps whereby the H_α line is set about the centre of detector frame. Table 1 listed all the program stars which consists of Be and Be-shell type of stars.

Table 1. The program stars

HD	HR	Name	Mag	Sp.type
205637	8260	ε Cap	4.62	B2.5 Ve, shell
214748	8628	ε PsA	4.20	B8 V
176269	7169	CrA	6.69	B9 V
157042	6451	Iot Ara	5.25	B2 IIIne
168905	6875	CrA	5.69	B2.5 Vn
196712	7890	-	6.22	B7 IIIne
143275	5953	δ Sco	2.30	B0.3 IV
127972	5440	Eta Cen	2.31	B1.5 Vne,shell
142184	5907	Sco	5.42	B2.5 Vn
158643	6519	51 Oph	4.81	B9.5 Ve
145389	6023	11 Her	4.26	B9 pe Mn
162732	6664	88 Her	6.68	Bep, shell
174638	7106	β Lyr	3.45	B7 Vpe, shell *
180968	7318	2 Vul	5.43	B0.5 IV
200120	8047	59 Cyg	4.74	B1 ne
166596	6804	CrA	5.47	B2.5 III
191639	7709	Cap	6.49	B1 V
209409	8402	31 o Agr	4.70	B7 IVe,shell
217050	8731	EW Lac	5.42	B4 IIIpe, shell

The spectral type of the program stars are taken from The Bright Star Catalogue, 5th Revised Ed. (Preliminary version) (Hoffleitt, 1991) except for the star with an asterisk mark (*) which is taken from The Sky Catalogue 2000.0. The spectral type of HD 200120 (HR8047) is variously classified: O9 V, B0 p, B1 IVe, B3 ne.

DATA REDUCTIONS AND ANALYSIS

All the reduction and analysis processes have been done using IRAF program. The bias noise was subtracted from the objects, dark current and flat-field frames to remove the bias level in all of the frames. At -10˚C the dark current number was still relatively high and thus need to be removed from the object frames. The dark subtracted object frames were then divided by the flat-field frame to remove all the defects fro m the instruments including the effects of variation on the pixel sensitivity. In IRAF program, the spectrum has to be extracted into one dimension image before it can be calibrated, normalized and analyzed.

Nineteen program stars were taken in the observations run. At a dispersion of 0.3 Å/pixel, we had identified 9 out of 19 stars having a double-peaked profile of H-alpha line. The equivalent width (eqw) and full width at half maximum (fwhm) of intensity were measured on a single absorption or peaked of FeII, HeI and H_α lines. Table 2 shows the values of eqw and fwhm, and rotational velocity, *V sin i* in column 6 was taken from the spectroscopic Be stars Atlas which was adopted from An atlas of Be stars, Paris-Meudon Observatory and from the catalogue of Be stars of Mr. Jaschek and D. Egret and asterisk marked values were referred from Catalogue of stellar rotational velocities (revised) by Uesugi (1982). The measurements of eqw and fwhm were conducted using IRAF by fitting a Gaussian profile.

RESULTS AND DISCUSSIONS

Spectra of the nineteen program stars were analyzed. It has been found that 9 of the stars have a double-peaked profile of H_α (HR 5440, 6451, 8260, 8731, 7106, 8402, 8628 and 6519) and HR 8047 (59 Cyg) has shown a triple-peaked emission line whereas an absorption line profile and a single-peaked emission line profile were found in HR 7169, 6875, 5907, 6023, 6664, 7318, 6804, 7709, and HR 7890 and 5953 respectively. We had noticed that HeI λ6678 was absent in HR6519 and HR6664 and it becomes an emission line in HR8047. A double-peaked profile was found in HR5953 and HR7106 which also shows a double-peaked in H_α. All of the spectra show the absorption line of FeII λ6516 as well as H_α line except that the value is relatively small. Figure 1 and 2 show the spectra of the program stars.

FWHM

The values of FWHM in table 2 were converted into km/s by dividing with 6678Å and multiplied with the velocity of light (300,000 km/s). Figure 3 shows the plots of FWHM of FeII, HeI and H_α vs V sin i were denoted respectively by square, triangle and circle marks. The graphs of FeII, HeI and H_α were respectively presented in solid, dotted and dashed lines. All the lines shows a slightly decreasing correlation between FWHM and V sin i.

The presents of double-peaked profile of HeI λ6678 in HR5953 (δ Sco) and HR7106 (βLyr) is probably related to its origin in the disk dynamics. The photospherical density and disk density changes were assumed probably time-dependent mass loss. When the mass loss increases, the disk density resulting from this increase becomes stronger, hence producing the double-peaked profiles whereby disk density changes control the observed variability in the equivalent width (Pollmann E., Leverkusen and Stober, B. 2007). Since HR5953 (δ Sco) and HR7106 (β Lyr) were also categorized as spectroscopic binary stars, the contribution from their companion should not be neglected. Figure 4 shows the double-peaked HeI 6678Å in HR5953 (δ Sco) and HR7106 (β Lyr).

Equivalent width, eqw

Equivalent width (eqw) measures the abundance of a line profile. We only consider FeII 6516Å and HeI 6678Å lines since most of them appeared as single line. Figure 5 and 6 respectively show the distribution of these lines along the spectral types and rotational velocity, *V sin i*. In figure 5, the dotted and strip bars represent HeI and FeII lines respectively. It was clearly seen that the eqw of HeI relatively higher for early type and reaches maximum at B3 and decreases towards the late type but for FeII the plots were rather scattered. In figure 6, the eqw of both lines shows a gradually decreasing correlation upon *V sin i* in which the gradient value of FeII is rather small compared to HeI that were shown by the equations in the graph.

Table 2. The values of equivalent width (eqw) and full width at half maximum (fwhm) of FeII λ6516, Hα λ6563 and HeI λ6678.

HD	**HR**	**Name**	**M_V**	**Sp.type**	**V sin i (km/s)**	**Fe II λ6516**		**He I λ6678**		**H-alpha λ6563**		**Remarks**
						Eqw (Å)	**Fwhm (Å)**	**Eqw (Å)**	**Fwhm (Å)**	**Eqw (Å)**	**Fwhm (Å)**	
205637	8260	ε Cap	4.62	B3 Ve	295	0.147	3.201	1.248	8.414			Hα double-peaked sb?
214748	8628	ε PsA	4.20	B8 Ve	375*	0.159	3.533	0.089	5.578			Hα double-peaked
176269	7169	CrA	6.69	B7/B8 V	172	0.268	4.020	0.057	3.056	8.256	18.440	sb
157042	6451	Iot Ara	5.25	B2 IIIne	390*	0.279	4.297	0.605	-0.609			HαDouble-peaked, m
168905	6875	CrA	5.69	B2.5 Vn	297	0.120	2.888	0.552	10.270			Hα abs line, m
196712	7890		6.22	B7 IIIne	250	0.158	2.671	0.087	2.517	-10.05	5.259	Single-peaked, sb
143275	5953	δ Sco	2.30	B0.5 IV	180	0.330	3.734			-15.780	6.092	He I double peaked, Hα peak not symmetry, sb
127972	5440	Eta Cen	2.31	B1 Vn+A	345*	0.480		0.766	5.347			HαDouble-peaked, sb
142184	5907	Sco	5.42	B2.5 Vn	300	0.323	3.807	0.618	10.060	3.122	12.460	Single peaked
158643	6519	51 Oph	4.81	B9.5 Ve	220*	0.302	3.439	-	-			Hα Double-peaked, He I absent
145389	6023	11 Her	4.26	B9 pe Mn	10	0.507	3.579	0.051	2.487	5.171	8.641	HeI very small, Hα broaden at baseline, sb
162732	6664	88 Her	6.68	Bep, shell	300	0.634	3.788	-	-			HeI absent, Hα broaden at baseline, sb
174638	7106	β Lyr	3.45	B7 Vpe, shell	120*	0.472	4.983					Hα & HeI double-peaked, sb
180968	7318	2 Vul	5.43	B0.5 IV	215	0.481	4.506	0.889	8.186	2.136	9.004	Hα, HeI – not symmetry, vb
200120	8047	59 Cyg	4.74	B1 ne	375	0.509	3.545	-0.343	8.384			Hα triple-peaked, sb
166596	6804	CrA	5.47	B2.5 III	197	0.163	1.960	0.958	6.253	1.386	5.091	Hα abs line
191639	7709	Cap	6.49	B1 V	205	0.385	3.821	0.981	8.121	1.770	8.718	Lines not symmetry
209409	8402	31 o Agr	4.70	B7 IVe	305*	0.286	3.198	0.126	6.173			Hα double peaked
217050	8731	EW Lac	5.42	B4 IIIpe	340*	0.402	3.183	1.027	6.134			Hα double peaked, sb

Notes:
sb? – a proven spectroscopic binary that may also be a visual binary sb – spectroscopic binary
vb – visual binary
sv – spectroscopic and visual binary
m – a star part of binary or multiple system
* - V sin i by Uesugi (1982)

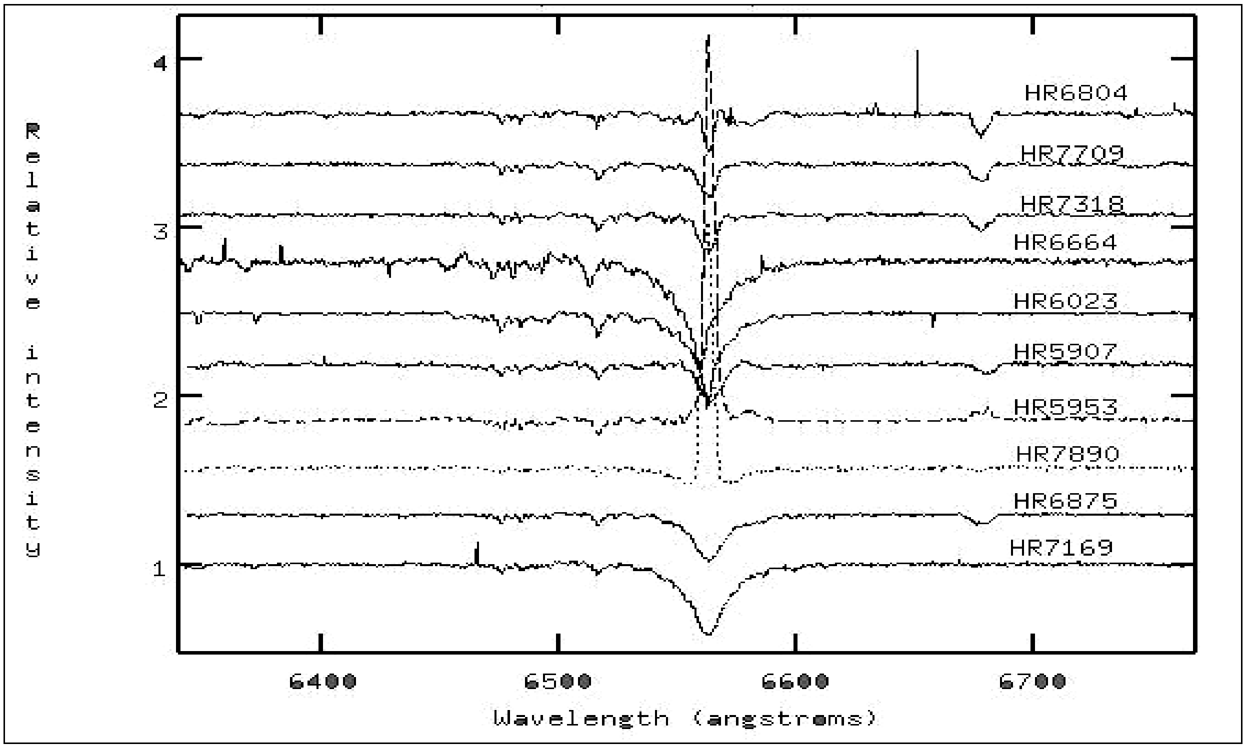

Figure 1. The spectra of program stars which exhibit a single emission/absorption line in H-alpha.

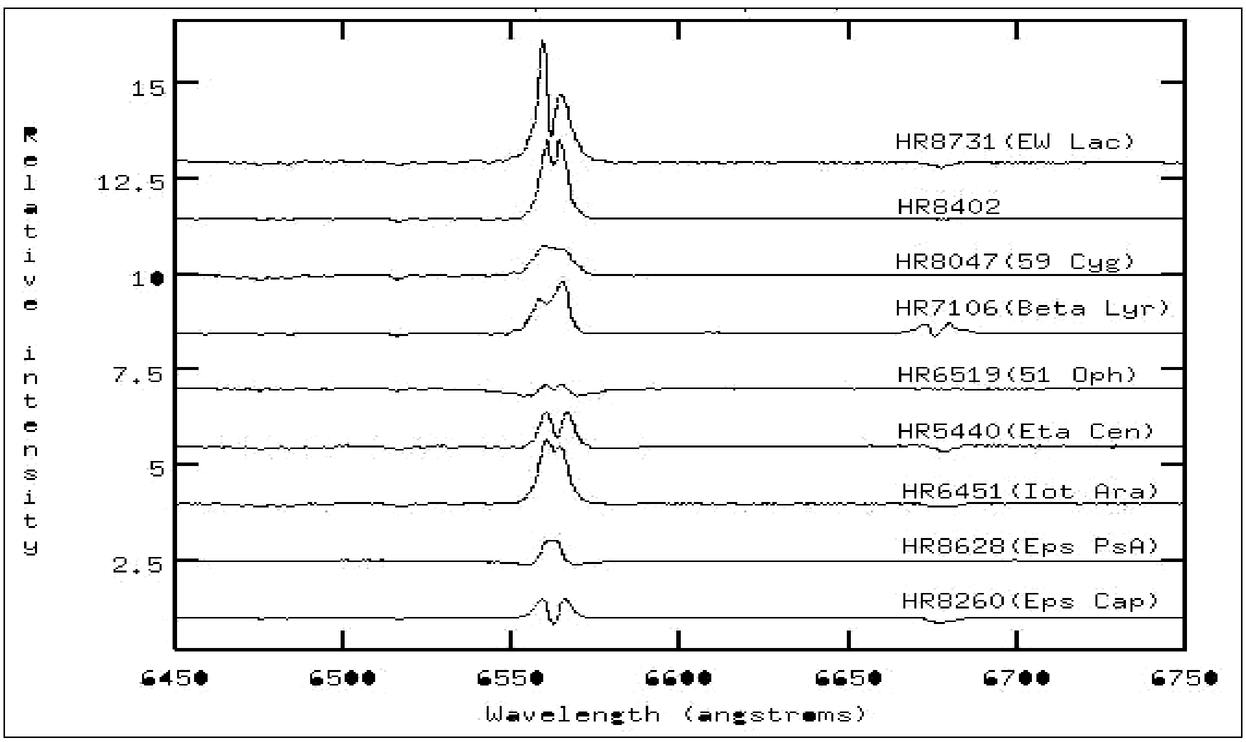

Figure 2. The program stars that show a double-peaked profile of H-alpha except for 59 Cyg

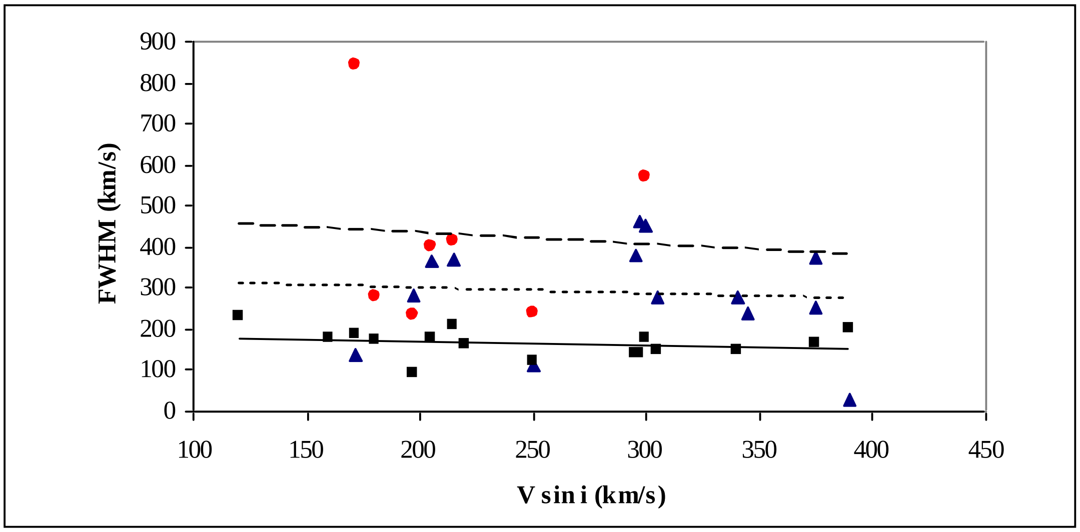

Figure 3. FWHM vs V sin i of FeII (square), HeI (triangle) and Hα (circle) lines. The dashed, dotted and solid lines represent the Hα, HeI and FeII lines.

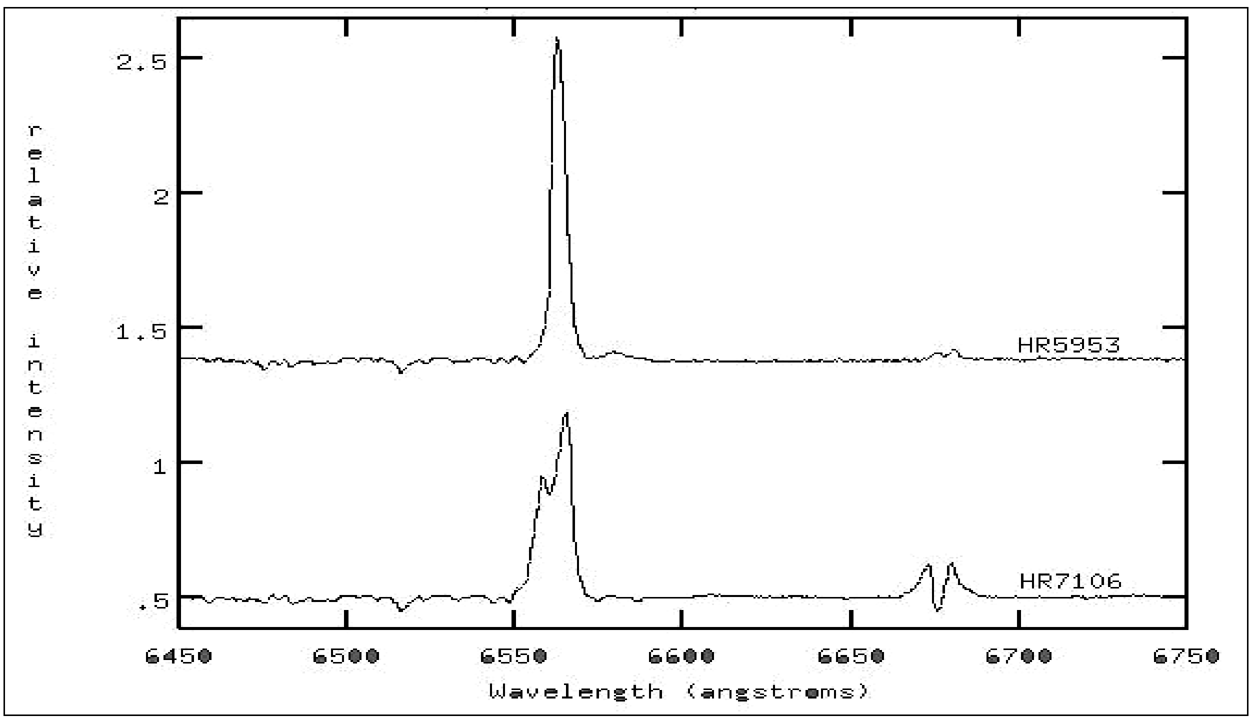

Figure 4. A double-peaked HeI in HR5953 (δ Sco) and HR7106 (β Lyr).

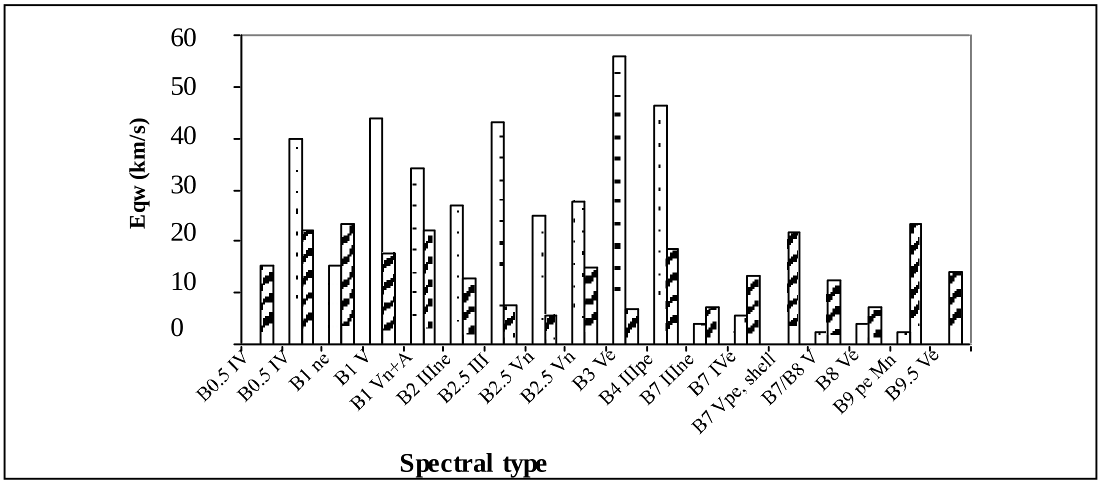

Figure 5. The equivalent width, eqw of FeII λ6516 (strip bar) and HeI λ6678 (dotted bar) vs spectral type.

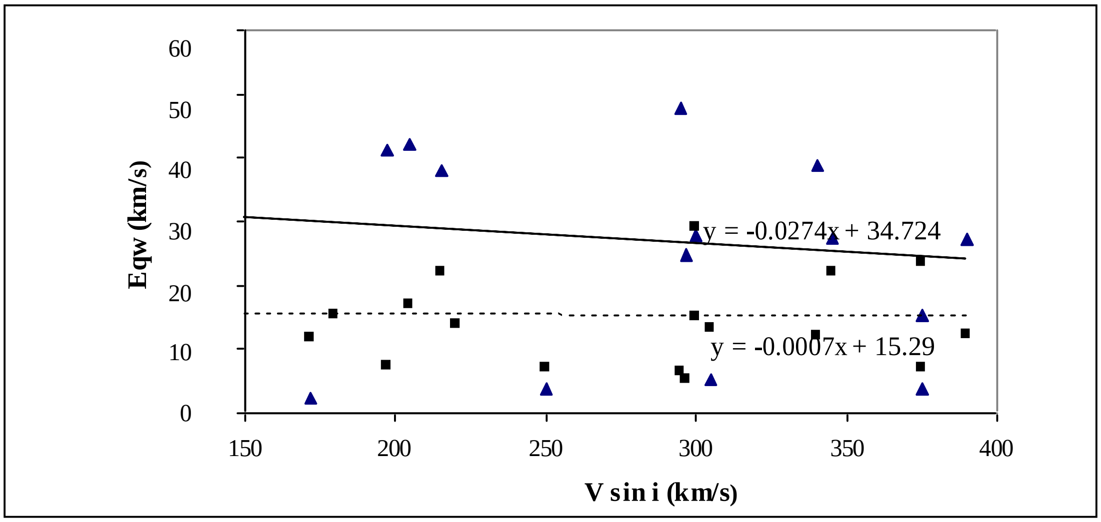

Figure 6. The plots of equivalent width, eqw of FeII (square) and HeI (triangle) vs. rotational velocity, V sin i. The correlation of both parameters for FeII and HeI were represented respectively by dotted and solid lines.

CONCLUSIONS

From the analysis on Hα line profile we found that 9 of the program stars are in Be-shell phase which show double-peaked profile, two stars are in Be phase showing a single- peaked emission line and the others are in normal B phase in which their Hα line appears in absorption line. The emission or absorption line width values such as FWHM or equivalent width are relatively stronger for HeI 6678Å than FeII 6516Å and the distribution upon spectral types shows a sign of activities rate in circumstellar shell/disk that the early type shows higher activities than the late type. This correlation is consistent with the values of Slettebak et al. (1994) and Mennickent et al (1994) which indicates that early-type Be stars have envelopes more developed than late-type Be stars (Kogure, T. and Leung, K.C. 2007). The slight decreasing feature of line width (FWHM) against the increasing V sin i shows in Figure 3 is somewhat different from the general view that the line width is larger in more rapidly rotating stars. Further observations are desirable to confirm the trend correlation. The studies of FWHM or eqw depend upon linearity of the flux scale derived, the resolution employed and S/N. Since these program stars are subjected to change in various forms and in various time-scales they require more series of observations in order to study their variations.

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