Optical control of a magneto-optical trap for cesium atoms

S Pradhan and B N Jagatap

Laser & Plasma Technology Division, Bhabha Atomic Research Centre, Mumbai 400 085, India

Email: bnj@barc.gov.in

Abstract. Loading of a magneto-optical trap for cesium atoms is studied in presence of an auxiliary (control) laser beam that is tuned to $6s_{1/2} F=4 \rightarrow 6p_{3/2} F'=4,5$ hyperfine manifold. It is shown that the steady state number of trapped atoms is enhanced or suppressed depending on the frequency, intensity and position of the control beam in the trap. The overall result is to provide an ability to optically control the number of trapped atoms without having to change the parameters of the trap. Detailed parametric studies of the control laser assisted optical manipulation of a MOT are presented.

1. Introduction

The magneto-optical trap (MOT) is a complex dynamical system that is rich in atom-field and atom-atom interaction processes [1-5]. Application of a near-resonant auxiliary laser beam can either enhance or suppress these basic processes and thereby provide an optical control over the characteristics of the MOT; specifically the number of trapped atoms ($N$). Such studies are useful for various experiments in quantum optics, cold collisions, precision measurements etc., for understanding of the MOT dynamics [1-3], and also for development of deterministic atom sources [6-8]. In the past several studies have been reported [9-13] where a near-resonant laser (‘catalysis’ laser) has been used to modify the collision dynamics of atoms trapped in a MOT and to yield an optical control over the inelastic collisions responsible for the trap loss. In these experiments the cold cloud of atoms in the MOT is illuminated by a catalysis laser, which enhances or suppresses the trap loss rate depending on whether the laser is tuned to the red or blue of the cooling transition.

Recently we demonstrated [14] enhanced loading of a Cs MOT by illuminating a small fraction of the capture region with an auxiliary laser (control laser) that is scanned over $6s_{1/2} F=4 \rightarrow 6p_{3/2} F'=5$ cooling transition. The control laser beam in this work illuminates only a small fraction of the capture region of the MOT instead of interacting with the cold cloud of atoms. In such a configuration $N$ is found to increase when the control laser is tuned in the vicinity of the cooling resonance and interestingly $N$ is maximized (2-3 fold increase) when the detuning is marginally on the blue (~ 4-5 MHz). The enhanced loading observed in these experiments is caused not by increase in the capture velocity as in the multi-frequency MOT configurations [15-17], but by removal of the Zeeman inaccessibility by the control laser beam through optical pumping [14]. These observations manifest the importance of the multi-level nature of the atoms in the magneto-optic trapping of neutral atoms in multi-frequency optical fields and also point to the possibility of optically manipulating the capture rate and thereby $N$ in a MOT.
In the previous publication [14] we were restricted to a relatively small range of parameters that covered only a part of the interesting region dealing with the optical control of loading of a MOT. In this paper we report detailed parametric studies to show that in general the control laser can enhance or suppress \( N \) depending on the choice of control parameters, thus providing a novel way of controlling \( N \) in a MOT. Enhancement and suppression result from two distinct processes that arise from the interaction of the control laser with two different groups of atoms, i.e., in the capture region and in the cold cloud. These processes combine to produce a general variation of \( N \), of which the results reported earlier are only a special case. The paper includes results of two sets of experiments: in the first the control laser is tuned in the vicinity of the \( 6s_{1/2}F=4 \rightarrow 6p_{3/2}F'=5 \) cooling resonance and the loading of the Cs MOT is studied as a function of the intensity and position of the control beam, and in the second the control laser is scanned over the entire \( 6s_{1/2}F=4 \rightarrow 6p_{3/2}F'=3,4,5 \) hyperfine manifold to involve an additional hyperfine level in the control dynamics. The paper, thus, illustrates a novel bichromatic MOT configuration that provides prospects for optical manipulation of \( N \).

2. Experimental
The experimental set-up is shown schematically in figure 1 and is similar to that described in our earlier work [14]. A standard \( \sigma^+ - \sigma^- \) six-beam MOT is formed by two diode lasers stabilized respectively on the cooling and repumping transitions of Cs, and by a pair of coils in the ‘anti-Helmholtz’ configuration to produce the desired spherical quadrupolar field. Each trapping beam has diameter \( d \sim 8 \) mm, detuning \( \delta \sim -3 \gamma \), where \( \gamma \) is the natural line width of the transition, and intensity \( I \sim 5-15 \) mWcm\(^{-2}\). The magnetic field gradients in the axial (\( z \) axis, along the symmetry axis of the coils) and radial (\( x-y \) plane) directions are \( \sim 22 \) Gcm\(^{-1}\) and \( \sim 11 \) Gcm\(^{-1}\) respectively. The background density (\( n_b \)) of Cs is controlled by using an isolating valve on the Cs reservoir and is monitored directly by absorption spectroscopy. The spatial extent of the cold cloud is measured using a charge couple device and \( N \) is obtained by measuring the steady state fluorescence intensity (\( I_f \)) of the cold cloud using a pre-calibrated light collection and detection system. We work with \( N \) in the range 0.1-1.0 \times 10^7 \) atoms, which means that the MOT is in the multiple scattering regime and also that the effect of intra-trap collisions is negligible. Typical rms sizes of the cloud are \( \omega_x = \omega_y = 2 \omega_z \sim 0.3 \) mm.

![Figure 1. Schematic representation of the experimental set-up. MOT lasers denote the diode lasers stabilized on the cooling and repumping transitions and CL is the control laser. The MOT beams in x and y directions are explicitly shown. PC: computer for control and data acquisition, SAS: Saturated absorption spectroscopy set-up, AM: Amplitude modulator for studying trap kinetics, OSC: storage oscilloscope, BS: beam splitter, M: mirror, Q: quarter wave plate.](image)
The control beam is a diode laser of an elliptical cross section with 3 and 1.7 mm of beam waists in the horizontal and vertical directions. The intensity ($I_c$) of the control laser is varied in the range 0.4-13 mWcm$^{-2}$. A small part of the control laser is used in a saturated absorption spectroscopy set-up with a Cs vapor cell to measure the detuning ($\delta_c$) of the control laser from the cooling resonance. The maximum uncertainty in the measurement of the relative frequency is ±2 MHz. The control laser is $\sigma$-polarized, made to co-propagate with the $\sigma_+$ cooling laser beam in x-direction and shifted spatially in x-y plane by a distance $s$ away from the centre of the cold cloud. For $s=0$ the control laser overlaps with the cold cloud and this position is marked by the vanishing of $I_c$ for a wide range of value of $I_c$ and $\delta_c$. The values of $s$ chosen for the experiments are 1, 3, 5 and 6 mm. For $s=1$ and 3 mm, a part of the control beam directly sees the cold atomic cloud while for $s=5$ and 6 mm it passes through the capture region of the MOT without interacting with the cold cloud of atoms.

We denote the extent of enhancement by $E = I_c^{(c)}/I_c^{(0)} = N^{(c)}/N^{(0)}$, where the superscripts, c and 0, signify respectively the measurements taken with and without the control laser. Thus $E > 1$ and $0 \leq E \leq 1$ indicate respectively the enhancement and depletion in $N$. The effect of the control laser on $N$ is studied in terms of the enhancement profile $E(\delta_c)$ obtained by scanning the control laser over $F=4 \rightarrow F'=3,4,5$ hyperfine resonances under the variation of the other experimental parameters. Each data point on $E(\delta_c)$ is an average of 25 observations. While in the earlier work we discussed a specific experimental situation for which $E(\delta_c)>1$, generally the experimental observations include both enhancement and depletion.

3. Results and discussions

We now present results of the experiments wherein the control laser frequency is tuned in the neighborhood of the cooling transition $F=4 \rightarrow F'=5$. Figure 2 shows the dependence of $E(\delta_c)$ on $s$ obtained by translating the control beam away from the trap center, i.e., $s \sim 1, 3, 5$ and 6 mm.

![Figure 2](image-url)

**Figure 2.** $E(\delta_c)$ as a function of position ($s$) of the control laser from the MOT center. Frames (a)-(d) correspond to $s=1,3,5,6$ mm respectively. Other experimental parameters are $I=5.4$ mWcm$^{-2}$, $n_b=3 \times 10^8$ and $I_c=5$ mWcm$^{-2}$, which yield $N^{(0)} = 1.8 \times 10^6$. 

3
Figure 2 exhibits two distinctive features of $E(\delta)$, namely depletion for $s \sim 1$ mm (figure 2a) and a single peak enhancement for $s \geq 5$ mm (figure 2c and 2d), while for $s \sim 3$ mm (figure 2b) $E(\delta)$ appears to be a combination of these two outcomes. For $s \sim 1$ mm the control beam illuminates a part of the cold cloud directly. In this situation the only noticeable effect is depletion of the cold cloud, which begins to occur at $\delta \sim 0$, and for $\delta = \delta_{\text{c}} \text{min} \sim 10$–15 MHz the trap becomes essentially empty. Beyond $\delta \sim 15$ MHz, the cloud starts to grow again and restores the intensity $I_f(0)$ for $\delta \geq 40$ MHz. For $s > 5$ mm, $E(\delta)$ is a pure enhancement profile with full width at half maximum $\Delta_c \sim 13$ MHz and peak at $\delta_{\text{c}} \text{max} = 3$ MHz for the parameters used in these experiments. This situation corresponds to $\sim 2.5$ fold enhancement ($E_{\text{max}} \sim 2.5$) in $N$ and significantly it occurs at the blue detuning of the control laser. As pointed out in the beginning $E(\delta)$ for $s \sim 3$ mm is an intermediate situation where the enhancement occurs up to $\delta \sim 0$ MHz and then it is overtaken by rapid depletion of atoms to empty the trap at $\delta_{\text{c}} \text{min} \sim 10$–15 MHz and thereafter restoration of the trap for $\delta > 40$ MHz. Such $E(\delta)$ are referred to as “mixed” (enhancement + depletion) profiles in this paper. For $s > 5$ mm $E(\delta)$ continues to be a single peak profile, however with reduced $E_{\text{max}}$ and increased $\Delta_c$. For example, at $s \sim 6$ mm, $E_{\text{max}} \sim 1.8$ for $\delta_{\text{c}}$ in the range 0–8 MHz, and $\Delta_c \sim 20$ MHz. Much away from the trap center the control laser makes a reduced overlap with the capture region and progressively addresses atoms with higher velocities, which may respectively result in decrease in $E_{\text{max}}$ and increase in $\Delta_c$.

It may be seen from figure 2 that there exist two distinct position dependent processes, one responsible for enhancement and the other for depletion. These processes are characterized by obtaining the trap loading and decay curves under the modulation of the control beam and analyzing the kinetics [18] to yield the atom capture rate ($R$) and the linear loss rate ($\alpha$). In these experiments the MOT lasers are held fixed while the control laser is modulated and the MOT fluorescence is measured in the ON as well as OFF intervals of the control beam to generate respectively the loading and decay curves. Typical values of the ON and OFF intervals are $\sim$2.5 and $\sim$1 s respectively and are characterized by detecting a part of the modulated beam on a photodiode. These experiments are conducted for the situation of figure 2b, which corresponds to a partial overlap of the control beam with the cold cloud and results in a mixed profile $E(\delta)$ with, $E_{\text{max}} \sim 2$ at $\delta_{\text{c}} \text{max} = 0$ MHz and $E_{\text{min}} = 0$ at $\delta_{\text{c}} \text{min} = 15$ MHz. The results are shown in figure 3, which also contains a loading curve obtained without the control beam for a direct comparison.

In the absence of the control laser MOT fluorescence reaches the steady state $I_f(0)$ and the corresponding loading curve (curve a) shows a characteristic rate constant ($\alpha$) $3.2$ s$^{-1}$. We now modulate the control laser while holding its frequency fixed at $\delta = \delta_{\text{c}} \text{max} = 0$ MHz. In the ON interval of the control laser the fluorescence grows from $I_f(0)$ and attains a new steady state $I_f^{(\alpha)}(\delta_{\text{c}} \text{max})$ and the rate constant for this growth (curve b1) is observed to be $3.6$ s$^{-1}$. In the OFF interval the fluorescence decays starting from $I_f^{(\alpha)}(\delta_{\text{c}} \text{min})$ and finally reaches $I_f(0)$ as time evolves. The characteristic rate constant for this decay (curve b2) is observed to be $3.4$ s$^{-1}$. The closeness of the magnitudes of the rate constants for curves a, b1 and b2 is not surprising since in all these situations the cold cloud is evolving under very similar experimental conditions, e.g. $n_c$. The growth curves a and b1 afford estimation of $R$ and the values are found to be $1.1 \times 10^2$ and $0.96 \times 10^3$ s$^{-1}$ respectively. The net effect therefore is to have $I_f^{(\alpha)}(\delta_{\text{c}} \text{max}) \sim 2 I_f(0)$ and consequently $E_{\text{max}} \sim 2$. Consider now the situation when the control laser is modulated while its frequency is held fixed at $\delta = \delta_{\text{c}} \text{min} = 15$ MHz. In the ON interval the fluorescence decays starting from $I_f(0)$ and reaches $I_f^{(\alpha)}(\delta_{\text{c}} \text{min}) \sim 0$ signifying complete emptying of the trap. The characteristic rate constant for this decay (curve c1) is found to be $12.5$ s$^{-1}$, which is much larger than the rate constants $3.4 \pm 0.2$ s$^{-1}$ observed for the curves a, b1 and b2. In the OFF interval of the control laser fluorescence grows and reestablishes $I_f(0)$ as time evolves (curve c2). The values of $\alpha$ and $R$ for this growth are found to be $3.5$ s$^{-1}$ and $1.2 \times 10^7$ s$^{-1}$, which are in agreement with the corresponding values observed for curves a, b1 and b2.
Figure 3. MOT loading and decay curves obtained under the modulation of the control laser beam and for $\delta_c = \delta_{c}^{\text{max}}$ (0 MHz) and $\delta_{c}^{\text{min}}$ (15 MHz) on $E(\delta_c)$ of figure 1b. Loading curve (a) is in the absence of the control beam and $I_f^{(0)}$ is the steady state fluorescence intensity. For $\delta_c = \delta_{c}^{\text{max}}$ ($\delta_{c}^{\text{min}}$) the fluorescence in the ON and OFF periods of the control laser is shown by the curves b$_1$ (c$_1$) and b$_2$ (c$_2$). The steady states of curve b$_1$ and c$_1$ are $I_f^{(\delta_{c}^{\text{max}})}$ and $I_f^{(\delta_{c}^{\text{min}})} \sim 0$ respectively. The modulation of the control laser is shown by the curve e.

The observations of figure 3 confirm that the origin of the enhancement is in increase in $R$, which is caused by the interaction of the atoms with the part of the control laser that overlaps with the capture region and it is most likely a result of the optical pumping of the inaccessible Zeeman states into the stretched states [14]. The mechanism responsible for depletion of the cold cloud has time constant that is much larger than the MOT filling time constant and we attribute this to the heating of the cold cloud by the part of the control laser that overlaps with the cold cloud. This heating process is particularly effective for blue detuning of the control laser and is maximized for $\delta_c = -\delta_{c}^{\text{max}}$. These conclusions are further supported by the results of figure 2. When the control laser is close to the cold cloud the heating mechanism dominates to cause depletion of atoms. On the other hand when it is sufficiently away from the cold cloud and spanning only the capture region, the process of enhancement dominates to result in increase in $N$, which is maximized for a marginally blue $\delta_c$. We may also note here that the observations of figure 3 provide a supporting evidence for actual increase (or decrease) in $N$ and rule out the possibility of increase (or decrease) in the MOT fluorescence without increase (or decrease) in $N$ since in those cases the fluorescence is expected to follow very closely the modulation of the control beam (curve e).

The profiles $E(\delta_c)$ are found to be strongly dependent on $I_c$. A special case of this was discussed earlier [14] for a pure enhancement case wherein a plot of $E_{\text{max}}$ vs $I_c$ was shown to attain a maximum. In more general situations $I_c$ is observed to modify the shape of $E(\delta_c)$. In figure 4 we show intensity dependence for a mixed profile $E(\delta_c)$ obtained for $s=3$ mm. Note in figure 4 the transition from the mixed (figure 4a and b) to pure enhancement (figure 4c) profiles when $I_c$ is reduced from 5 to 1.8 mWcm$^{-2}$. On decreasing $I_c$ still further, $E(\delta_c)$ is marked by reduction in $E_{\text{max}}$ and increase in $\Delta_t$, together
with a noticeable blue shifting of $\delta_c^{\text{max}}$. For example in figure 4 on going from $I_c = 1.8$ to 1.0 mWcm$^{-2}$, the values of $(E_{\text{max}}, \Delta, \delta_c^{\text{max}})$ change from $\sim (2, 10\text{MHz}, 3\text{MHz})$ to $\sim (1.6, 16\text{MHz}, 5\text{MHz})$, while for $I_c = 0.55$ mWcm$^{-2}$ (not shown in figure 4) the corresponding values are $\sim (1.2, 18\text{MHz}, 6\text{MHz})$ respectively. It appears that the effect of decreasing $I_c$ is qualitatively similar to that of increasing $s$. For large $I_c$, a sizable overlap of the wings of the control beam with the cold cloud can cause significant depletion in $N$ for $\delta_c > 0$ MHz. This overlap reduces with progressive reduction in $I_c$ resulting in the appearance of a pure enhancement profile. At sufficiently low $I_c$ the noticeable blue shift in $\delta_c^{\text{max}}$ may arise from resonance of the control beam with Zeeman shifted levels.

**Figure 4.** Dependence of $E(\delta_c)$ on $I_c$ for fixed $s=3$ mm. Frames (a)-(d) correspond to $I_c=5.0$, 3.0, 1.8 and 1.0 mWcm$^{-2}$ respectively. Other experimental parameters are $I=5.4$ mWcm$^{-2}$ and $n_c=2\times10^8$ which give $N(0)=1.2\times10^6$.

When the experimental conditions are such that they favour enhancement, it is observed that the increase in $N$ is accompanied by corresponding increase in the size of the cloud and that the spatial distribution is enlarged symmetrically even though the control laser is acting only on one side of the capture region. This can be conveniently observed by recording the spatial profile of the cloud before and after enhancement using fluorescence imaging technique. A typical result of such experiments is displayed in figure 5 for a specific set of parameters of the control beam that result in enhancement. The spatial profile of figure 5 then allows for quantification of the cloud volume ($V$) and changes therein. We follow the changes in $N$ and $V$ over a single peak $E(\delta_c)$. A plot of $V$ vs $N$ is shown in figure 6, which clearly shows that the density of the cold cloud remains nearly constant during enhancement. Note here that in this experiment $N \sim 10^8$ and density $\sim 10^{10}$ cm$^{-3}$. For $N > 10^7$ atoms the sample is in the multiple scattering regime [3], where the reabsorption of scattered photons becomes important. The key feature of the multiple scattering regime is that the density becomes independent of $N$ and consequently the cloud grows in size as more number of atoms are added during the enhancement process.
The size of the cloud has an important bearing on the behaviour of \( E(\delta_c) \) since it governs the relative overlap of the control beam with the cold cloud and the capture region, which is responsible for the extent of depletion and enhancement. Consequently in the multiple scattering regime \( E(\delta_c) \) becomes dependent on the MOT parameters that are responsible for increase in \( N \). For example, for a fixed position of the control beam that yields a pure enhancement profile at low \( N \), becomes dependent on the MOT parameters that are responsible for increase in \( N \). For example, for a typical single peak \( E(\delta_c) \) which is generated using \( I=7 \) mWcm\(^{-2} \), \( I_c=1.6 \) mWcm\(^{-2} \), \( n_0=2\times10^8 \) and \( s\approx 5 \) mm. First data point is without the control laser while the points 2-4 correspond to \( \delta_c = -6, -3 \) and 0 MHz on the enhancement profile. Each data point is an average of 10 samples.

We now present a few key observations for the control laser scanned over the entire hyperfine manifold \( F=4\rightarrow F'=3,4,5 \). In general \( E(\delta_c) \) undergoes marked changes in the vicinity of all resonances, but its behaviour is both qualitatively and quantitatively different at each resonance. These differences arise mainly from the differences in transition strengths \( S_{FF'} \) and from the inclusion of an additional level (\( F'=3,4 \)) in the laser-atom interaction dynamics. The process of enhancement as well as the
depletion by heating is directly related to \( S_{FP} \). In addition \( S_{FP} \) determine the absorption losses of the control beam in the path of the background Cs vapour, so that each resonance experiences different intensity near the trap center to manifest an indirect intensity dependence. Participation of an additional level in the dynamics is imminent when the control laser is tuned to \( F=4 \rightarrow F'=3,4 \) hyperfine resonances. In these situations, the transitions \( F=4 \rightarrow F' =5 \) and \( F=4 \rightarrow F'=3,4 \) generate a V configuration \(^{[19]}\) with an additional excitation \( F=4 \rightarrow F'=4 \) by the repumping laser, and in general the dynamics is expected to be complicated. The simplest case corresponds to the optical pumping of \( F=4 \) level into \( F=3 \) level, which can provide an additional mechanism for depletion of \( N \). Consequently when the control laser is partially overlapping with the cold cloud, one of the observed features of \( E(\delta_c) \) includes mixed behaviour near \( F=4 \rightarrow F'=5 \) resonance while complete depletion at \( F=4 \rightarrow F'=3,4 \) resonances, particularly at large \( I_c \).

Under a very careful choice of parameters it is possible to control the loading characteristics of the MOT at each hyperfine resonance. However the relative degree of enhancement and suppression near these frequencies is remarkably different owing to the dissimilar dependence on position and intensity of the control beam. This is illustrated in figure 7 where we have shown three examples of \( E(\delta_c) \) obtained by tuning the control laser across \( F=4 \rightarrow F'=3,4,5 \) manifold. For convenience \( \delta_c \) is measured with respect to the \( F=4 \rightarrow F'=5 \) resonance as before and with this convention the field-free resonances \( F=4 \rightarrow F'=3,4 \) are located at \( \delta_c = -452.2 \) and \(-251.0 \) MHz respectively. Figure 7a displays a situation that corresponds to the single peak enhancement at all hyperfine transitions. These results are obtained at low \( n_b \) so that the indirect intensity dependence arising from the absorption of the control laser in the Cs vapour is negligible and that \( N \) is small to minimize the effect of the cloud size even when the control beam is relatively closer to the trap center. The choice of \( I_c \) is such that it helps enhancement at
We have shown here that an auxiliary laser beam added to a Cs MOT and tuned over the 6s$_{1/2}$F=4 → 6p$_{3/2}$F'=3,4,5 hyperfine transitions follow the order of $S_{FF}$ and that underlines the role of transition strengths in the mechanism responsible for enhancement. We, however, do not observe $E_{\text{max}}$ in the same ratios as $S_{45}:S_{44}:S_{43} = 6.3:3:1$ for Cs atom. This may be attributed to the intensity dependence of $E_{\text{max}}$. It has been shown earlier [14] that in case of a single peak enhancement near F'=4→F'=5 resonance $E_{\text{max}}$ maximizes at $I_\text{c}$ that is close to the saturation intensity and decreases at higher values. The results of figure 7a correspond to $I_\text{c}$ that is above the saturation intensities of F'=4→F'=4,5 transitions. The observed values of $\delta_{\text{max}}$ for F'=4→F'=3,4,5 transitions are −454, −251 and +1 MHz and these correspond to the detuning of −2, 0, +1 MHz with respect to the respective resonances. Within the experimental error, this trend appears to be in the order of the $g_{F'}$, which are respectively 0, 4/15 and 2/5 for F'=3,4,5. Figure 7b shows another interesting example of $E(\delta_\text{c})$, which exhibits a strong single peak enhancement at ~2 MHz on the red of F'=4→F'=3 resonance and a mixed behaviour near F'=4→F'=4,5 resonances. The experimental conditions of figure 7b are same as in figure 7a except that the overlap of the cold cloud with the control beam is increased by moving the beam closer to the trap center and by marginally increasing $n_\text{b}$. A consequence of increase in the overlap is to set off the depletion mechanism but its effect on $E(\delta_\text{c})$ at each resonance appears to be directly related to $S_{FF}$. The effect is severe at F'=4→F'=5 and negligible at F'=4→F'=3 while the resonance F'=4→F'=4 shows an intermediate result. A comparison of figure 7a and figure 7b shows that while the enhancement and depletion are both dependent on $S_{FF}$, their interplay is governed by the position of the control beam relative to the cold cloud. This position dependence is further highlighted in figure 7c, which contains results obtained for the parameters of figure 7b except that $n_\text{b}$ is increased by two fold to boost $N$ and thereby the cloud size. The overlap of the cloud with the control beam is therefore stronger in case of figure 7c. This results in transforming $E(\delta_\text{c})$ at F'=4→F'=3 resonance from a single peak (cf. figure 7b) to a mixed enhancement profile and also in reducing the enhancement component of the profile at F'=4→F'=4 resonance. Finally we note in figure 7 that at each hyperfine resonance whenever depletion occurs it maximizes when the control laser is on the blue of the respective transition.

4. Conclusions

We have shown here that an auxiliary laser beam added to a Cs MOT and tuned over the 6s$_{1/2}$F=4 → 6p$_{3/2}$F'=3,4,5 hyperfine transitions enables us to vary the number of cooled and trapped atoms. This variation is a result of the interplay of two distinct position dependent processes, one responsible for enhancement and other for depletion. Interaction of the control beam with the atoms in the capture region results in the enhancement in the number of trapped atoms. This is caused by an increase in the capture rate and possible mechanism involves optical pumping of inaccessible Zeeman states into the stretched states by the control laser [14]. Position and intensity dependence of the enhancement profiles provides evidence for participation of Zeeman levels in the interaction dynamics. The enhancement of the number of trapped atoms is accompanied by the proportionate increase in the size of the cloud to keep the density constant. Suppression occurs when the control beam interacts with a part of the cold cloud and maximizes at frequencies that are blue with respect to the individual hyperfine resonances. This is attributed to the heating of the cloud by blue detuned frequencies resulting in the expulsion of the atoms from the trap. These two processes, depending on the relative overlap of the control beam with the capture region and the cold cloud, combine to produce a general variation in the number of trapped atoms, which can be controlled by the position, intensity and frequency of the control beam. The ability to vary the number of trapped atoms without changing the MOT operating conditions makes this study interesting and potentially useful for controlling the number of trapped atoms necessary for various experiments [6-8] and also for studies of the dynamical and collisional properties of a MOT. Finally the results presented here are also important in understanding of the space dependent effects in the magneto-optic trapping of atoms.
Acknowledgments
Authors thank Dr. K G Manohar and Dr. S J Gaur for many useful discussions and comments.

References
[1] Lindquist K, Stephens M and Wieman C 1992 Phys. Rev. A 46 4082
[2] Gibble K E, Kasapi S and Chu S 1992 Opt. Lett. 17 526
[3] Townsend C G, Edwards N H, Cooper C J, Zetie K P and Foot C J 1995 Phys. Rev. A 52 1423
[4] Weiner J, Bagnato V S, Zilio S and Julienne P S 1999 Rev. Mod. Phys. 71 1
[5] Metcalf H J and van der Straten P 2003 J. Opt. Soc. Am. B 20 887
[6] Ruschewitz F, Bettermann D, Peng J L and Ertmer W 1996 Europhys. Lett. 34 651
[7] Kuhr S, Alt W, Schrader D, Muller M, Gomer V and Meschede D 2001 Science 293 278
[8] Yoon S, Choi Y, Park S, Kim J, Lee J -H and An K 2006 Appl. Phys. Lett. 88 211104
[9] Marcassa L, Muniz S, Queiroz E de, Zilio S, Bagnato V, Weiner J, Julienne P S and Suominen K -A 1994 Phys. Rev. Lett. 73 1911
[10] Katori H and Shimizu F 1994 Phys. Rev. Lett. 73 2555
[11] Suominen K -A, Holland M J, Burnett K and Julienne P 1995 Phys. Rev. A 51 1446
[12] Walhout M, Sterr U, Orzel C, Hoogerland M and Rolston S L 1995 Phys. Rev. Lett. 74 506
[13] Wallace C D, Sanchez-Villicana V, Dinneen T P and Gould P L 1995 Phys. Rev. Lett. 74 1087
[14] Pradhan S, Gaur S J, Manohar K G and Jagatap B N 2005 Phys. Rev. A 72 053407
[15] Anderson B P and Kasevich M A 1994 Phys. Rev. A 50 R3581
[16] Sinclair A G, Riis E and Snadden M J 1994 J. Opt. Soc. Am. B 11 2333
[17] Flemming J, Marcassa L G, Horowicz R J, Zilio S C, and Bagnato V S 1995 Opt. Lett. 20 2529
[18] Browaeys A, Poupart J, Robert A, Nowak S, Rooijakkers W, Arimondo E, Marcassa L, Boiron D, Westbrook C I and Aspect A 2000 Eur. Phys. J. D 8 199
[19] Yan M, Rickey E G and Zhu Y 2001 J. Opt. Soc. Am. B 18 1057